Handbook on N_2O Mitigation Experience in Germany/Europe

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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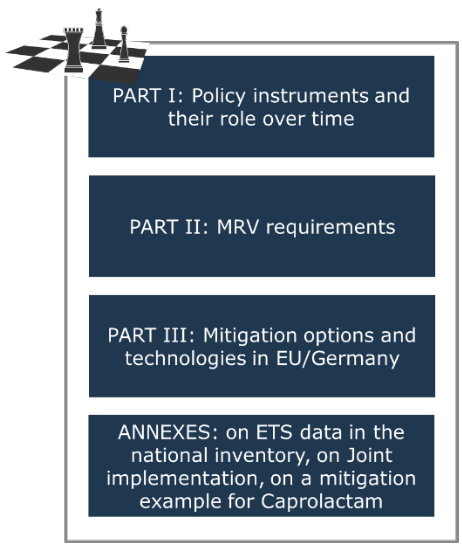
Executive Summary

N_2O mitigation action at chemical industry facilities is a large and cost-effective lever for reducing greenhouse gas emissions globally. This applies to emissions from nitric acid, adipic acid and caprolactam production alike. With a climate neutrality target for 2060 in place, the PRC may well use this considerable potential to advance its decarbonization efforts and thereby effectively contribute to the implementation of the Paris Agreement.

This report aims at providing guidance for selecting the adequate instrument and to establish a conductive environment for this mitigation action. It looks at the implementation side of the task, bringing together German experiences from the use of two different pricing instruments that helped and continue to help Germany and the EU bring down its industrial N_2O emissions at low cost. The first one is the most mature emissions trading system in the world, the EU ETS. It effectively puts a price on N_2O emissions in the relevant sectors and functions via a cap-and-trade approach. In China the reference case is the national ETS that applies so far to the energy sector only.

The second pricing instrument is the voluntary offset instrument Joint Implementation (JI) that incentivized mitigation action by means of establishing a market where certificates are handed out for certified mitigation outcomes. Here China has its own extensive hands-on experience from implementation of the Clean Development Mechanism (CDM), JI's older sibling program, with many projects in the sector of adipic acid, nitric acid and caprolactam production.

Both the compliance and the voluntary systems have much in common. But they differ on relevant aspects. This report looks at these differences, providing take-aways from the mitigation practice in Germany. It thereby helps distil and structure lessons learned that can inform the policy making process for an upcoming framework in China.



The study starts with a general introduction to the various policy approaches including the two market-based instruments that have played a critical role in the EU for regulating N_2O emissions from the chemical industry facilities.
Part II then looks at the various aspects in the emissions accounting and the framework used for implementation. Aspects from both instruments may well help establish and refine a robust and conductive system for N_2O emissions accounting in China.

Part III then turns to the technology side, describing the implementation of various abatement options for nitric acid and adipic acid production sites in Germany. On abatement efficiency and costs, it wraps-up information from other studies.
The Annex to the report includes four dedicated sections. They are (a) a short excursus on the use of ETS data in the national inventory, (b) one primer on joint implementation, (c) another on the accreditation system in Germany as a special feature in the verification environment, and (d) an exemplary technical implementation case at a Caprolactam production site in Belgium.

How to read the document

This report follows a logical structure. Thus, it may be read cover-to-cover. But it also may be used for learning and reference purposes regarding certain aspects. Here an interested reader may start from the table of contents, looking at sections of special interest. The cross-referencing throughout the document shall help familiarize readers with relevant aspects in the broader context of an issue. The marker (⇒) helps start excursus-wise journeys into respective aspects that are presented in various sections.

For policy makers of special interest are the legislative background (part I), lessons learnt from the MRV systems (part II) as well as the dedicated Annexes on ETS data use in the national inventory or on the accreditation system.

For operators of special interest are the specifics on the MRV (part II) as well as the overview of available abatement options and of their efficiency and cost (part III). Moreover, a dedicated Annex presents one illustrative implementation example at a Caprolactam site in Europe. Together, the information casts light on monitoring and reporting requirements that come with robust emissions accounting and on the general options for mitigation action.

List of abbreviations

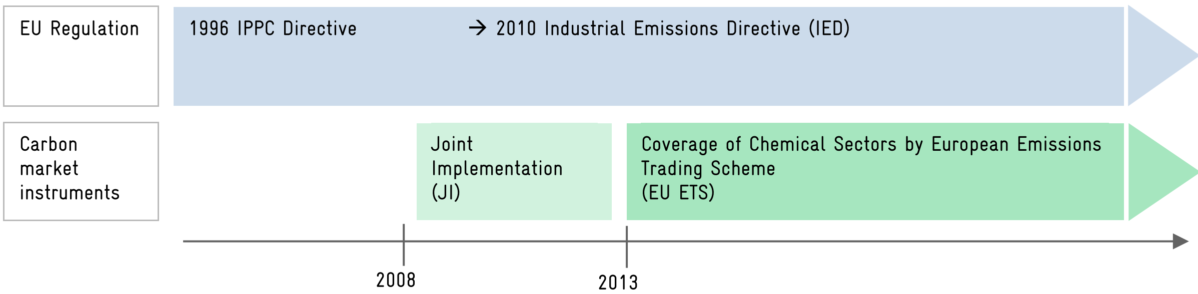
AAU	Assigned Amount Unit (see glossary)
AIE	Accredited Independent Entity (see glossary)
AMS	Automated Measuring Systems (see glossary)
AST	Annual Surveillance Test
AVR	Accreditation and Verification Regulation (see glossary)
BAT	Best Available Technology (see glossary)
BREF	Best Available Techniques Reference Documents (see glossary)
CA	Competent Authority (see glossary)
CDM	Clean Development Mechanism (see glossary)
CEFIC	European Chemical Industry Association
CEMS	Continuous Emissions Monitoring Systems (see glossary)
CEN	European Committee for Standardisation
CER	Certified Emission Reductions (see glossary)
CO_2	Carbon Dioxide
CO_{2e}	Carbon Dioxide Equivalent (see glossary)
DAKks	Deutsche Akkreditierungsstelle
DEHSt	Deutsche Emissionshandelsstelle
DFP	Designated Focal Point (see glossary)
DIN	German Industry Standards

DMS	Data Management System
EFMA	European Fertilizer Manufacturers Association
EHV	Emissions Trading Ordinance
ELV(s)	Emission Limit Values (see glossary)
E-PRTR	European Pollutant Release and Transfer Register
ERU	Emission Reduction Unit (see glossary)
EU	European Union
EUA	European Union Allocation
EU ETD	European Union Emissions Trading Directive (see glossary)
EU ETS	European Union Emissions Trading System (see glossary)
EU MRR	European Union Monitoring and Reporting Regulation (see glossary)
GHG	Greenhouse gases (see glossary)
HNO_3	Nitric Acid
IED	Industrial Emissions Directive (see glossary)
IPCC	Intergovernmental Panel on Climate Change (see glossary)
IPPC	Integrated Pollution Prevention and Control (see glossary)
ISO	International Organization for Standardization
JI	Joint Implementation (see glossary)
JISC	Joint Implementation Supervisory Committee (see glossary)
MRV	Monitoring, Reporting and Verification (see glossary)
NACAG	Nitric Acid Climate Action Group
MP	Monitoring plan
NH3	Ammonia
N_2O	Nitrous oxide
NSCR	Non-Selective Catalytic Reduction
PDDs	Project Design Documents
ProMechG	Act on Project-Based Mechanisms JI and CDM
QAL1	Suitability Testing
QAL2	Adequate Functionality
QAL3	Routing Quality Testing
SCR	Selective Catalytic Reduction
SO_2	Sulphur dioxide
TEGH	Greenhouse Gas Emissions Trading Act
UBA	German Umweltbundesamt

Part I: Policy instruments and their role over time

This section describes the main policy instruments targeting N_2O (nitrous oxide) emissions from the chemical industry in the European Union (EU). Before the mid-90s, air pollution control was not coordinated on the European level. Member states had different approaches towards emissions from industry and N_2O did not play a role, as it was not considered to be a pollutant. In fact, voluntary agreements were the first 'instrument' to mention N_2O with its role as an important greenhouse gas and committed to reduce it. Therefore voluntary agreements are covered below within the chapter about Joint Implementation (JI) projects, as they benefitted indirectly from this incentive scheme.

A landmark policy instrument introducing environmental standards for the industry across Europe was the Integrated Pollution Prevention and Control (IPPC) Directive, adopted in 1996. It aimed at an integrated approach to target pollution through air, water, and waste by defining best available technologies and mandating industry to adapt those over time. In practice, this meant thresholds and deadlines for individual installations determined by the respective environmental permits. This changed with the market-based instruments, which turned the abatement of greenhouse gases into a business model. From 2008-12, it was possible for a plant ⇒operator [glossary] to earn carbon credits under the JI mechanism for dedicated N_2O abatement activities. In 2013, several chemical industry sectors were integrated in the European Union Emission Trading Scheme (EU ETS), including nitric acid and adipic acid production with their N_2O emissions.



In the following, we describe policy instruments and how they affected N_2O emissions from nitric acid and adipic acid production.

1 EU regulation on industrial emissions

1.1 The IPPC: Overview

Adopted in 1996 as a set of general guidelines for authorising industrial installations and their environmental impact, the Integrated Pollution Prevention and Control (IPPC) Directive was a key instrument of the EU to enforce and harmonize environmental standards for industrial production in the EU. As a directive, it applies to the member states, mandating them to transpose it to national law and implement the necessary regulation, institutions, and processes to make it applicable to plant operators in the concerned industry sectors. Annex I of the directive defines the industrial activities and capacity thresholds to which the rules applied. In consequence, approximately 52,000 plants were covered EU-wide. Those plants need – as prerequisite for operation – an environmental permit issued by a national or subnational ⇒competent authority (CA) [glossary]. The application for such a permit includes information on activities, material streams, energy generation and use and substances generated by the individual plant and emissions associated with them. Moreover, proposed technology along with emission techniques on emission monitoring, mitigation, and alternative solutions must be indicated. Compliance deadlines differentiated between existing and new installations: Installations which were about to undergo 'substantial changes' as well as new installations were expected to comply with the IPPC Directive from 30 October 1999 on, whereas all other installations were expected to do so by 30 October 2007.
Key principles of the IPPC Directive are the/an integrated approach, best available technologies (BATs), flexibility, and public participation.

1. **The integrated approach** takes the overall environmental performance of the plant into consideration engaging all processes within its operation and ensuring a high degree of natural resource preservation.
2. The **BATs** are aimed at the determination of permit conditions along with Emission Limit Values (ELVs). The Commission is responsible for the exchange of information between EU experts, industry, and environmental organisations, thereby supporting licensing authorities and company representatives in identifying BATs. This activity is managed by the European IPPC Bureau of the Institute for Prospective Technology Studies at the EU Joint Research Centre in Seville (Spain), resulting in the publication of BATs reference documents, also known as BREFs, published in the official languages of the EU.
3. The IPPC Directive is quite **flexible** and allows the licensing authorities to consider (a) the technical characteristics of the installation, (b) the geographical location of the installation, and (c) its topographical and ecosystem characteristics when issuing a permit/setting emission limits.
4. The directive gives the **public** the right to **participate** in the decision-making process and obtain information on (a) permits, (b) applications for permits to be able to further express their opinion, (c) results of emission monitoring of the plants, (e) the European Pollutant Release and Transfer Register (E-PRTR). Once member states report their emissions data, this information is published in a public register where the user is invited to inspect information on the industrial activities of companies.

1.2 Best Available Technology Reference Documents (BREFs)

As described above, the Best Available Techniques Reference Documents (BREFs) represent the outcome of the 'Seville process', covering the industrial activities listed in Annex 1 to the EU's IPPC Directive and provide the descriptions of a range of industrial processes and their respective operating conditions and emission rates. The Member States are subject to conduct an explicit investigation of industrial installations and provide full compliance with the directive. The representatives from various industries along with the Commission and the Member States are expected to network on BATs, which serve as a foundation for determining emission limit values.

There are two main BREFs covering the production of inorganic (nitric acid) and organic (adipic acid and caprolactam) chemical compounds. The Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilisers (LVIC-AAF) BREF was formally adopted in 2007, while the Large Volume Organic Chemicals (LVOC) BREF went through several iterations since 2001 and has been published as part of a European Commission Implementing Decision in 2017 in its most recent version.

1.3 Nitric acid

This BAT is aimed at reducing emissions of N_2O from the production of nitric acid to achieve the emission factors or emission concentration levels given in Table I by applying a combination of the following techniques:

- optimising the filtration and mixing of raw materials
- optimising the gas distribution over the catalyst
- monitoring catalyst performance and adjusting the campaign length
- optimisation of the NH_3/air ratio
- optimising the pressure and temperature of the oxidation step
- N_2O decomposition by extension of the reactor chamber in new plants
- catalytic N_2O decomposition in the reactor chamber
- combined NO_x and N_2O abatement in tail gases.

Table I.1.3.1: N_2O emission levels associated with the application of BAT to produce HNO_3 (nitric acid).

		N_2O emission level[x]	
		kg/tonne 100 % HNO_3	ppmv
M/M, M/H and H/H	New plants	0.12 – 0.6	20 – 100
	Existing plants	0.12 – 1.85	20 – 300
L/M plants		No conclusion drawn	

[x]The levels relate to the average emission levels achieved in a campaign of the oxidation catalyst

1.4 Adipic acid

In case the N_2O from adipic acid production is not reused, there are two widely used end-of-pipe techniques – catalytic decomposition and thermal destruction. Catalytic decomposition uses metal oxide catalysts (e.g. MgO) to decompose the N_2O into N_2 and O_2. Thermal destruction involves the combustion of a mixture of the offgases and methane, where N_2O acts as an oxygen source and is reduced to nitrogen, giving emissions of NO and some residual N_2O. The combustion process can be used to generate steam.

According to the LVOC BREF, N_2O abatement has been already in place at facilities in Europe since the 1990s. For example, reduction furnace technology was developed by Bayer in 1994, whereas the other German manufacturer, BASF, installed a catalytic system at their Ludwigshafen plant in 1997. In June 1998, the French company Alsachimie, a subsidiary of Rhodia, brought a system onstream to convert N_2O to nitric acid at their Chalampe site. However, there are no further specific limitations concerning N_2O defined in the LVOC BREF.

1.5 Caprolactam

Modified caprolactam production processes are mainly affected by the elimination of the high volumes of ammonium sulphate that are produced as a by-product of the conventional process (Reimschuessel, 1977; p.84). NH_3 oxidation remains an integral part of all processes to obtain the NO/NO_2 required. The HPO plant has emissions of cyclohexanone from tank vents and vacuum systems, toluene tank vent emissions, and NO_X and NO_2 from the catalytic NO_x treatment unit. The HSO plant has emissions of cyclohexanone and benzene from tank vents and vacuum systems, sulphur dioxide (SO_2) emissions, and NO_x and NO_2 from the catalytic NO_x treatment unit. Waste gases from the HPO and HSO plants are used as fuel or flared. Waste gases with nitric oxide and ammonia are converted to nitrogen and water over a catalyst.
However, N_2O emission levels are not specified in the respective BREF in the context of caprolactam.

1.6 Conclusion

It is obvious that the adipic acid and caprolactam chapters of the BREFs do not put much importance on N_2O emissions. For adipic acid, this is partly explained by the fact that abatement technologies were already in place at that time. In the case of caprolactam, it seems that production techniques and processes and the resulting N_2O emission levels are so heterogenous that no common sense on adequate BAT was achievable.

In the case of nitric acid plants, the IPPC's effectiveness with respect to N_2O abatement seemed limited, too. One of the main reasons was that even the October 2007 deadline for existing installations to comply with BAT N_2O emission levels was in many cases not enforced, partly due to late implementation by member states. It turned out that JI and (the expectation of the) incorporatiion into the EU ETS outpaced the IPPC regulation on the way to N_2O abatement.

2 Baseline & credit: JI projects

2.1 Legal framework for generating carbon credits with JI projects in Europe

The legal basis for both the recognition of credits from the Clean Development Mechanism (CDM) and JI projects under the EU ETS and the implementation of JI projects within the EU was set in the year 2004 by an amendment to the existing EU Emissions Trading Directive (EU ETD). This amendment is also called the "linking directive," as it was supposed to link different crediting schemes with each other so as to provide better access to and incentives for mitigation activities outside the EU ETS system boundaries. As EU directive, it had to be implemented (and substantiated) by member states. On the directive's level, basic provisions were defined, *inter alia*

- Member states should define upper limits for the use of credits from CDM and JI projects against each installation's commitment under the EU ETS, defined as percentage share of individual free allocation (allocation as the basis was later changed to verified emissions, since not all installations received free allocation after 2012).
- The necessity to establish a registry to keep track of Emissions Reduction Unit (ERU)[1] issuance and balancing with Assigned Amount Unit (AAU) budget (International Transaction Log).
- Avoidance of double counting, especially with emissions covered by the EU ETS.
- Adherence to conservative baseline scenarios that were at least in line with any kind of applicable EU regulation that was to be adopted by member states under the acquis communautaire.
- Publication of project-related information.
- Specific safeguards for large hydro projects.
- Responsibility of member states for overall compliance with United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol rules.

These provisions were implemented in Germany by the Act on Project-Based Mechanisms JI and CDM ('ProMechG') from 2005. The act translated the European Provisions to German law, defined the approval procedures and responsibilities and referred to JI rules under the UNFCCC for specific rules and standards. The legal framework for baseline setting in Germany consisted of the following elements:

1 Emission Reduction Unit: The term for carbon credits generated under the JI scheme.

German Project Mechanisms Act **(ProMechG)**
§ 5 sets the rules for JI projects in Germany

↓ refers to

Appendix B to the annex to decision 9/CMP.1 **(JI Guidelines)**
sets criteria for baseline setting and monitoring

↓ is taken up within the

Guidance on Criteria for Baseline Setting and Monitoring **(JISC Guidance)**
published by the JI Supervisory Committee (JISC) at its fourth meeting

The Joint Implementation Supervisory Committee (JISC) Guidance, in accordance with decision 10/CMP.1, offers two basic options for the establishment of a baseline:

1. Using an approved CDM baseline methodology.
2. Establishing a project specific baseline that is in accordance with Appendix B of the JI Guidelines with the option of using selected elements or combinations of approved CDM methodologies or tools, as appropriate.

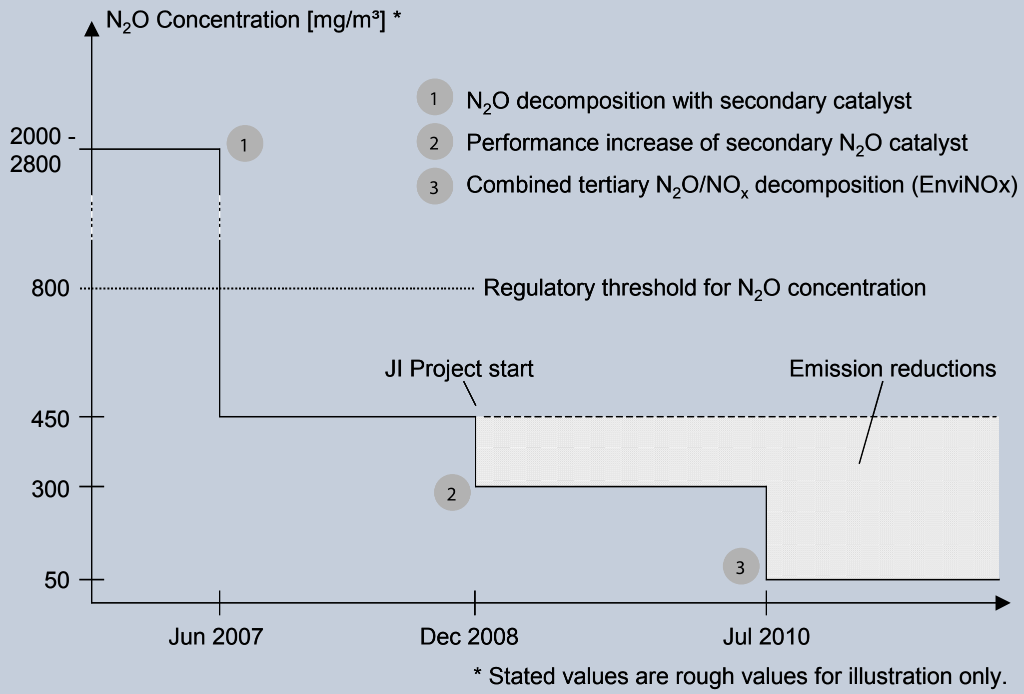
This approach allowed enough flexibility for project developers to use existing CDM methodologies even in cases which had originally not been considered by the methodology. For instance, CDM methodologies for N_2O abatement (at that time AM0028 and AM0034 for nitric acid and AM0021 for adipic acid) assumed a baseline scenario with no N_2O abatement. However, the typical baseline measurement campaign approach for the derivation of a plant specific N_2O emission factor was also applicable to the numerous situations where N_2O abatement had already been in place before project implementation. Those projects consisted of enhancing the N_2O abatement level. The already existing abatement level had to be reflected in the baseline scenario (*cf.* both case studies).

Accordingly, most JI projects in Europe applied (adapted) CDM methodologies to derive the baseline scenario, demonstrate additionality, set project boundaries, determine project emissions, and define the monitoring procedure. In practice, this meant that most projects had to go through a baseline measurement campaign in order to determine the applicable baseline emission factor and assess and discuss any applicable emission limits from national or regional implementation of the IPPC directive. France, however, went a step further by defining specific benchmark emission factors to be applied in calculating the baseline for nitric acid projects. At a minimum, 2.5 $kgN_2O/tHNO_3$ (1.85 from 2012 on) had to be applied as baseline emission factor, unless local authorities specified even lower emission levels as part of the plant permit. Since this rule was applicable to any plant, irrespective of the actual emission level, a baseline measurement campaign became dispensable and the lead time to project start could be reduced.

Case Study: Carbon market instruments succeeding previous regulation

A closer look at the nitric acid plant of Ineos Manufacturing Deutschland GmbH, located close to the city of Cologne, illustrates how the carbon market instruments (Joint Implementation and Emissions Trading Scheme) provided an incentive for investments into further N_2O reduction even in the case of already installed abatement technologies.

At the time of preparing for a JI project aiming at the stepwise further reduction of N_2O emissions from nitric acid production (2008), secondary N_2O abatement had already been implemented. In its PDD[2], the project developer presented a diagram to illustrate the N_2O emissions/abatement path underlying the idea of the JI project:



In compliance with applicable German regulation (implementing the European IPPC directive), a revised plant permit from the year 2005 mandated the operator to reduce N_2O emissions below the maximum threshold of 800 mg/m³ in the tail gas from 1 January 2008 onward. As a consequence, a layer of secondary N_2O decomposition catalyst has been installed in the ammonia reaction chamber in June 2007 (measure (1) in the diagram), resulting in a N_2O concentration in the tail gas of approximately 450 mg/m³. In applying a conservative baseline approach (following CDM methodology AM0034 and an accordant baseline measurement campaign), this – already comparably high – abatement level was reflected in the baseline emissions level of 1.4 kgN_2O/t nitric acid. The subsequent measures (performance upgrade of secondary abatement (2) and the installation of a N_2O/NO_x destruction facility in the tail gas (3)) led to even lower N_2O emission levels and were rewarded with the issuance of carbon credits under the JI scheme until the end of 2012. This end date was the consequence of the inclusion of nitric acid plants into the European Emissions Trading Scheme (EU ETS).

Under the EU ETS, nitric acid plants received a free allocation calculated as the product of a historical annual nitric acid production and the benchmark of 0.302 allowances/$tHNO_3$. Any actual emission level below that benchmark led to surplus allowances under the EU ETS between 2013 and 2020. The revised benchmark value for free allocation in the period 2021-2025 is 0.230.

2 Formerly publicly available at the German project database: https://www.dehst.de/EN/climate-projects_maritime-transport/project-mechanisms/project-database/projectdetails_node.html?cms_idProjekt=3168

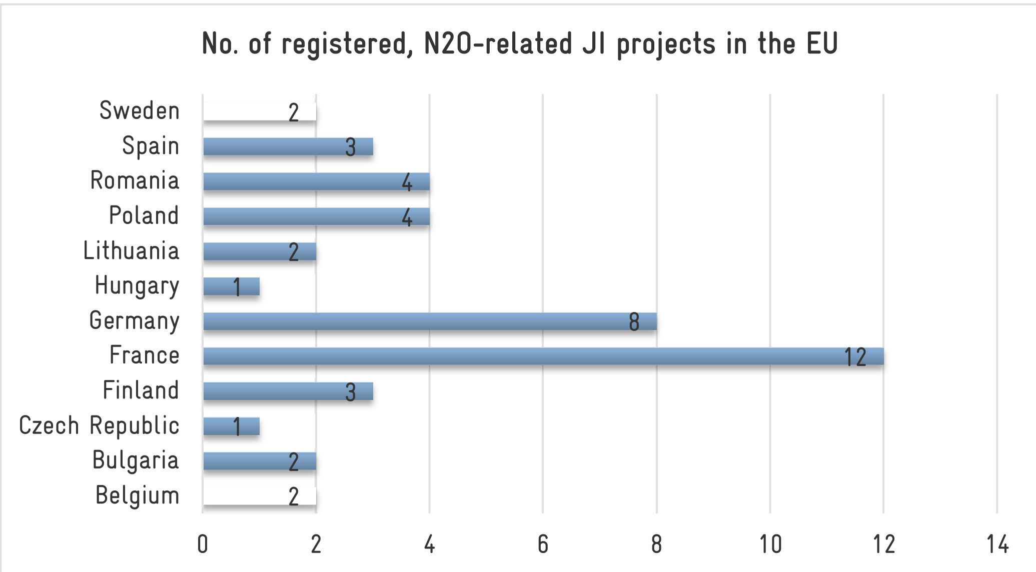
Since the actual emission level which can be achieved with efficient tertiary abatement technology lies far below those thresholds, the investment into N_2O abatement measures turned out to be an attractive business case for plants in Europe. For the nitric acid plant in Cologne, the reward for N_2O abatement was as follows:

Phase/Instrument	JI project 2008-12	EU ETS 2013-20	EU ETS 2021-25
Total Issuance/Surplus	684,050 ERUs issued[3]	914,487 EUAs surplus[4]	...

2.2 Role of JI for N_2O abatement in the chemical industry

Of the total 604 JI projects approved and registered between 2008 and 2012 under track 1 and 2, 46 projects were associated with N_2O emissions from nitric and adipic acid production.[5] With some 57 million ERUs issued for these projects; N_2O abatement represents some 6.6% of total ERU issuance, ranking fourth in the list of issuances by project type.
Out of those 46 N_2O-related JI projects, 44 were located in EU member states:

Figure I.2.2.1: N_2O-related JI projects per EU member state.



Again, out of those 44 projects, 41 took place at nitric acid plants and only 3 at adipic acid (2 in Germany and 1 in France).

3 Cf. JI Pipeline Overview available at http://cdmpipeline.org/

4 Cf. European Union Transaction Log: https://ec.europa.eu/clima/ets/oha.do

5 UNEP DTU Analysis of CDM/JI projects, available at cdmpipeline.org (accessed in October 2021).

2.3 Role of voluntary commitments of industry sectors

Voluntary agreements with industry sectors have a certain tradition in Germany. Even though the fact that industry helps determining limits and obligations for themselves has the potential to draw criticism, they are also regarded as a reasonable tool in situations where the combination and novelty of (environmental or social) needs, potential measures and technologies comes with complexities that can hardly be understood and solved by policy makers alone. A dialogue between industry representatives (in most cases organized as industry associations in Germany and Europe) and policy makers leads to an agreement, where the industry sector commits to reaching defined targets (e.g. greenhouse gas (GHG) emission reductions) and in turn avoid the imposition of new regulation or obligations in the same field, at least for a certain period of time. Such voluntary commitments can therefore be seen as replacing regulation, while the industry sector is incentivized to achieve the targets to maintain its authority and credibility for future cooperation with policy makers.

In 1995, a broad initiative by 15 German industry associations resulted in a 'declaration of the German industry regarding climate protection,' which is widely seen as rather symbolic and ineffective.[6] However, revisions of this declaration in the years 1996 and 2000 brought more participation, more ambition, and more commitment. Almost 75% of domestic carbon dioxide (CO_2) emissions in the year 1990 were represented in the latest agreement. Amongst other things, industry committed to reduce specific emissions of the six Kyoto gases by 35% between 1990 and 2012. In particular, the chemical industry promised 35-40% reduction of specific energy consumption and 45-50% reduction of energy related CO_2 emissions and N_2O-emissions.[7] In turn, the German government pledged neither to introduce mandatory energy audits nor new regulation with respect to energy efficiency and CO_2 reduction, as well as giving industry interests particular consideration in the field of environmental taxes. In retrospect, the mentioned commitments from the year 2000 were exceeded in 2012 by the participating industries in total. In particular, N_2O emissions from nitric and adipic acid plants went down from 23.8 $mtCO_{2e}$ in 1990 to 1 $mtCO_{2e}$ in 2012.[8] However, the accordant investments into abatement measures were rather the result of IPPC implementation and its anticipation (at least for nitric acid plants) and of JI projects. The two adipic acid plants in Germany installed N_2O destruction facilities as part of voluntary commitments in the 1990s and then added additional (redundant) abatement facilities as part of JI projects in 2008 and 2009 (one of them presented in the case study below).

6 Fritz Söllner: Die Selbstverpflichtung als umweltpolitisches Instrument, August 2002, in Heft 8 des Wirtschaftsdiensts.

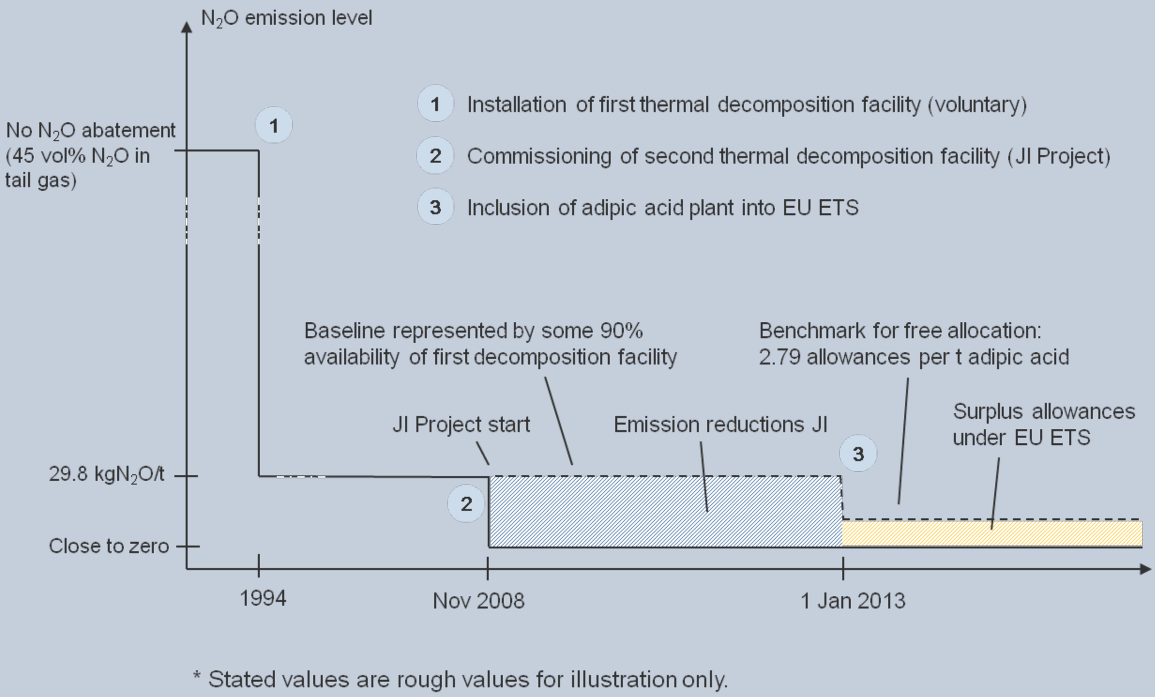
7 RWI: Die Klimavorsorgeverpflichtung der deutschen Wirtschaft – Monitoringbericht 2011 und 2012, Oct. 2013

8 RWI, table 5.4, p. 87

Case Study: Voluntary commitment as conservative baseline for a JI project

In 2006, with the prospect of generating carbon credits under JI from 2008 on, the operator of the adipic acid plant in Krefeld-Uerdingen, LANXESS, took the installation of a second thermal N_2O destruction facility into consideration. The first thermal destruction facility went into operation in 1994 with the primary purpose of bringing NO_x emissions below the regulatory thresholds. At that time, no obligation to reduce N_2O existed. However, as part of the chemical industry's voluntary commitment, LANXESS chose to use thermal decomposition technology, so that both NO_x and N_2O emissions could be reduced. This first thermal decomposition facility at an adipic acid plant in Europe proved highly efficient in reducing N_2O concentration in the tail gas, down from some 45 percent by volume to nearly zero. However, during intended and unplanned downtimes of the thermal decomposition facility, the tail gas was led via the SCR (selective catalytic reduction) facility, which eliminated the NO_x, but did nothing to the N_2O concentration in the gas that was released to the atmosphere. The availability of the thermal decomposition facility over the year was in the range of 85 to 90% on average.

The idea of the JI project was to install a second thermal decomposition facility so that unabated release of N_2O to the atmosphere could almost completely be avoided.



With this redundant N_2O decomposition facility in place, LANXESS was able to generate significant volumes of carbon credits under the JI scheme despite the quite conservative baseline. After 2012, the low N_2O emission rate continued to be rewarded under the EU ETS, where free allocation, based on a benchmark of 2.79 allowances per ton adipic acid, left a surplus of EUAs for the operator. The revised benchmark for free allocation in the period 2021-2025 is 2.12.

Phase/Instrument	JI project 2008-12	EU ETS 2013-20	EU ETS 2021-25
Total Issuance/Surplus	3.245 million ERUs issued[9]	1.538 million EUAs surplus[10]	...

These carbon credits were the revenue for the investment into the redundant thermal decomposition facility, which, according to the PDD, cost roughly 10 million EUR.

9 Cf. JI Pipeline Overview available at http://cdmpipeline.org/

10 Cf. European Union Transaction Log: https://ec.europa.eu/clima/ets/oha.do

3 Cap & trade: The EU Emissions Trading Scheme (EU ETS)

The EU Emissions Trading Scheme (EU ETS) has been in operation since 2005. It covers the energy sector, major industry sectors with emissions-intensive manufacturing processes and aircraft operators.[11]

The scheme operates in distinct trading phases, where each phase is characterized by an *ex-ante* fixed cap of allowances that are made available to the installations (mainly via auctioning and free allocation). The coverage, allocation rules and other aspects of the trading scheme were revised and refined from phase to phase, to strengthen the incentives for operators to reduce emissions, reflect the ambition of the EU's overall climate targets, harmonize rules throughout member states and enhance flexibility on the supply side to react to changes in the market.[12]

The major change for the chemical industry was the inclusion of several of its sub-sectors and gases with the start of phase 3 (2013-2020), including nitric acid and adipic acid production. As a result of this enlargement, coverage of the EU ETS rose to more than 11,000 power stations and industrial plants in 31 countries, responsible for around 50% of EU GHG emissions in the third phase.

3.1 Distribution of allowances

While in the first two phases of the EU ETS (2005-07 and 2008-12), most of allowances were handed out for free to ETS participants[13], the basic principle of allocation from 2013 on shifted to auctioning. Anyway, industrial and heating sectors still received free allocation, based on GHG performance benchmarks (described in detail below). Just the power generation sector was, with certain exceptions, subject to 100% auctioning from 2013 onwards. Industry sectors were supposed to receive free allocation following a decreasing path, starting with 80% in 2013, down to 30% in 2020. However, even this concept of transitional free allocation did not play a relevant role in free allocation to industry sectors, due to a wide-ranging application of the carbon leakage concept.

In order to limit the risk of shifting production/emissions to outside the EU due to increased costs associated with climate policies for operators within the EU (so-called carbon leakage risk), installations in concerned sectors received 100% allocation rather than the above described descending 80-30%. Whether a sector or sub-sector was exposed to a significant risk of carbon leakage was mainly determined based on a set of quantitative criteria, namely direct and indirect additional costs induced by the EU ETS and the non-EU trade intensity. In phase 3, most industry sectors were deemed to be exposed to a significant carbon leakage risk, representing over 90% of total free allocation. The carbon leakage assessment was slightly revised for phase 4 for a more targeted definition of carbon leakage sectors. Nitric acid and adipic acid have been on the

11 Cf. Annex I of the ETS Directive: http://data.europa.eu/eli/dir/2003/87/2018-04-08.

12 A good overview of the elements of the EU ETS and their evolution over time is provided by the EU Commission's EU ETS handbook: PDF download at https://ec.europa.eu/clima/document/download/8cabb4e7-19d7-45bd-8044-c0dcc1a64243_en.

13 In phase 1 largely by grandfathering, which is why the first phase was a kind of pilot phase to learn from for future revisions of the EU ETS.

carbon leakage list since 2013 and keep being CL-sectors, because their sectors meet both the carbon cost and trade intensity criteria.[14]

The following (simplified) formula sums up and helps to illustrate the above-described allocation logic:

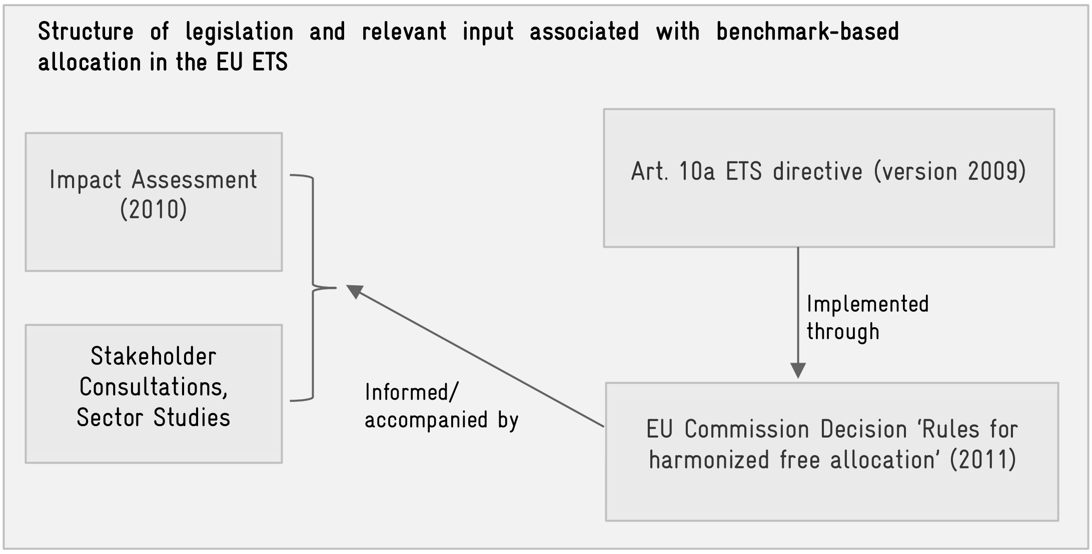
Allocation = Historical Production x Benchmark x Carbon Leakage Factor x CF

Average or median annual production level from a historical period (e.g. 2005-08 or 2009-10 for phase 3).	Product benchmark (alternatively fallback benchmarks), see details below.	100% for sectors with carbon leakage risk, 80-30% for sectors which are not on the CL-list.	Correction factor or linear reduction factor to keep allocation within the cap.[15]

The benchmarks are described in more detail below.

3.2 Benchmarks

The legal basis for the establishing the system of product benchmarks for free allocation in phase 3 (2013-2020) was set by Article 10a of the ETS directive, titled 'Transitional [...] rules for harmonized free allocation.'



Art. 10a defines a couple of basic principles for the establishment of a benchmark-based allocation scheme:

- No free allocation for electricity production (with exceptions).
- Application of benchmarks to products rather than inputs (to incentivize GHG reductions/efficiency measures).
- Consultation with relevant stakeholders, including sectors and sub-sectors concerned.

14 Carbon leakage lists are revised every five years and can be found on the EU Commission's website: https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets/free-allocation/carbon-leakage_en.

15 Not further treated here.

- Definition of *ex-ante* benchmarks, i.e. that benchmark-based installation-level allocation shall be fixed prior to the start of the respective trading period.
- Average performance of the 10% most GHG-efficient installations in a sector or subsector as starting point for benchmark setting.

The last point – the top-10% rule – is obviously the one with the most significant impact on the quantification of benchmark levels. It triggered comprehensive activities within Europe aiming at gaining a thorough understanding of the emission rates within the industry sectors, resulting in sector-specific benchmark curves. Industry sector associations played an important role in the data collection for measuring the greenhouse gas performance of ETS installations. Based on defined rules, the so-called 'sector rule books' with guidance on quality and verification criteria, they helped to gather the necessary data from the plant operators. The EU Commission carried out in-depth compliance checks and analysed whether the resulting starting points (top-10%-values) sufficiently reflected the most efficient techniques, substitutes, alternative production processes and other best-available-practice aspects of GHG performance.

The resulting list of benchmarks to be applied for calculating free allocation to installations from 2013 on consisted of 52 product benchmarks, covering around 75% of industrial EU ETS emission. Two more benchmark values – for measurable heat flows and for fuel use – were defined for so-called fallback approaches to be applied in all those cases where deriving a product benchmark turned out not to be feasible. Several further detailed rules were part of the Commission Decision that resulted from the above-described procedure and contained the benchmark values.[16]

3.2.1 Product benchmark for nitric acid

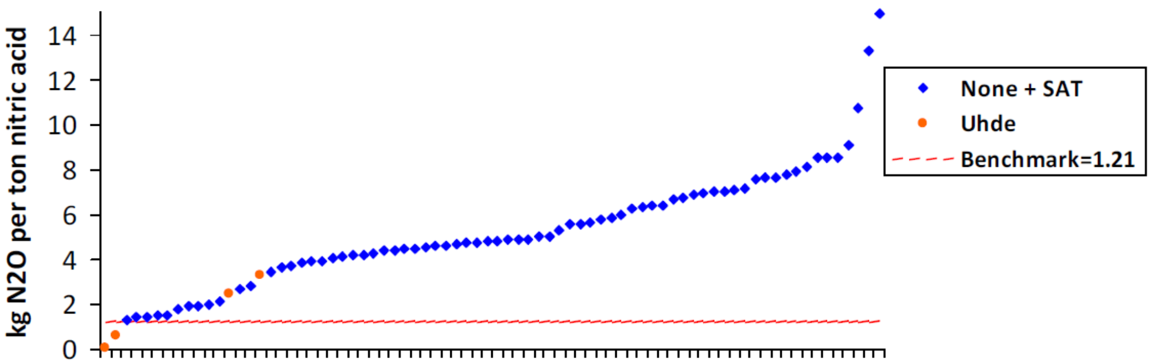
One of those 52 product benchmarks had been developed for nitric acid. With annual emissions of 41 $MtCO_2$-equivalents in 2006, nitric acid production was the most emission intensive activity in the chemical sector in Europe. The above-described procedure for collecting the necessary data involved European Fertilizer Manufacturers Association (EFMA), who again commissioned an independent auditor company to carry out the actual benchmarking study, including survey, data collection, data processing and conclusions. 90 nitric acid plants out of the 115 plants in the EU-27 (at that time) were covered by the study, which aimed at generating benchmark curves based on the actual GHG performance of the surveyed plants in the years 2007/08. Different observations and characteristics of this industry sector gave reason for discussion:

- Differentiation of low/medium/high pressure plants, single vs. dual pressure plants. In Europe, all types exist, with medium/high plants being most common.
- N_2O abatement: In 2007/08, some nitric acid plants in Europe had some form of N_2O abatement techniques installed. Where N_2O abatement was a result of Non-Selective Catalytic Reduction (NSCR) (primarily for NO_x abatement, but also with effect on N_2O), it was argued that this should not be considered for benchmarking because NSCR was not supposed to be best available technology for N_2O abatement.
- Since most nitric acid plants produce and export steam, it had to be determined whether the benchmark would also cover steam.

16 Commission Decision of 27 April 2011 determining transitional Union-wide rules for harmonized free allocation of emission allowances […], see http://data.europa.eu/eli/dec/2011/278/oj.

Due to such and more differences in plant characteristics, the GHG performance of nitric acid plants in Europe was very heterogenous. This became visible in the resulting benchmark curves:

Figure I.3.2.1.2: N_2O emissions from EFMA nitric acid plants 2007-08, excluding plants with NSCR: 83 plants in EU27.[17]



Using this benchmark curve, the resulting benchmark (average performance of the top 10% most efficient installations of the plants) would have been 1.21 kgN_2O/tHNO_3 (which equates to 0.36 tCO_{2e} per tHNO_3,[18] where HNO_3 is expressed in 100% nitric acid). More options had been discussed in the above cited study and the accompanying stakeholder consultation. In the end, the benchmark value adopted by the EU Commission for free allocation for nitric acid plants in phase 3 (2013-20) was 0.302 allowances per tHNO_3 (100%) and covered the steam generation from the exothermic process.

The following is an extract from the table with the product benchmarks in Annex I of the EU allocation and benchmarking decision:

Table I.3.2.1.2: Benchmark description for nitric acid and adipic acid in Annex I of the EU allocation decision.

Product benchmark	Definition of products covered	Definition of processes and emissions covered (system boundaries)	Benchmark value (allowances/t)
Nitric acid	Nitric acid (HNO_3), to be recorded in tonnes HNO_3 (100% purity).	All processes directly or indirectly linked to the production of the benchmarked product as well as the N_2O destruction process are included except the production of ammonia.	0.302
Adipic acid	Adipic acid to be recorded in tonnes of dry purified adipic acid stored in silos or packed in (big)bags. Salts and esters of adipic acid are not covered by this product benchmark.	All processes directly or indirectly linked to the production of the benchmarked product as well as the N_2O destruction process are included.	2.79

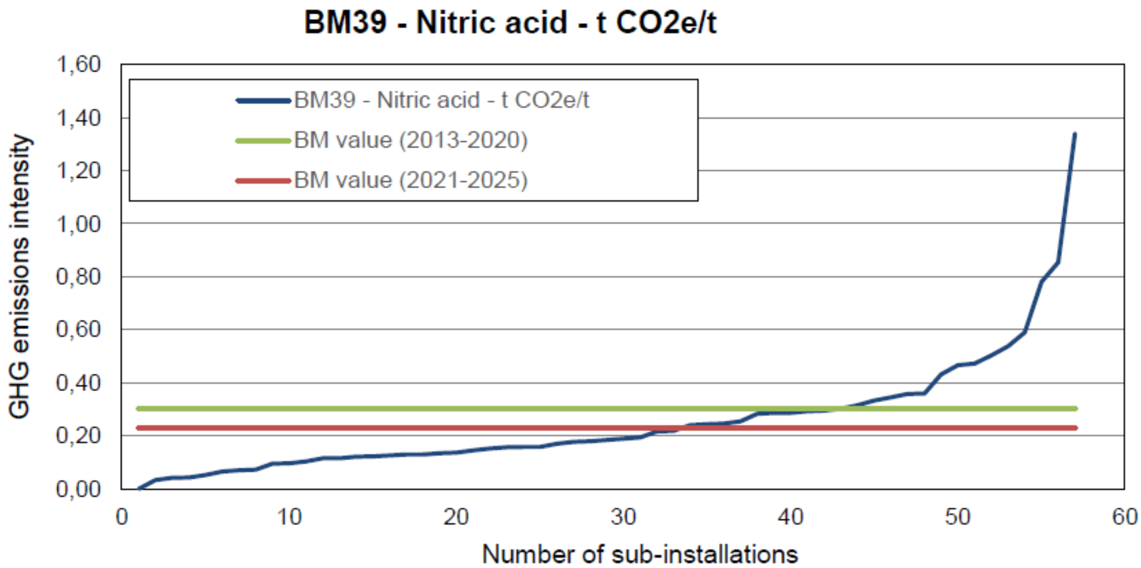
17 Taken from Ecofys et al: Sector report for the chemical industry, November 2009, https://ec.europa.eu/clima/document/download/b5e9cb5a-ff10-4a89-a083-e69663b708d3_en.

18 The Global Warming Potential used for N_2O in 2013-20 was 298.

Revision for phase 4

The picture of nitric acid plants' GHG emissions intensity had changed dramatically when the 2016/17 data were evaluated for the benchmark update for phase 4 of the EU ETS (starting 2021). The new benchmark curve was/is built on data from 57 installations (instead of 83 in 2007/08), which indicates significant changes within the industry. The evaluation of the new data revealed an average GHG emission intensity of the top 10% most efficient installations in 2016/17 of 0.038 $tCO_{2e}/tHNO_3$, around one tenth of the level nine years before. This was confirmed by absolute emissions data: the GHG emissions from those 57 installations averaged to some 4.3 $MtCO_{2e}$ between 2016/17. These changes became visible in the new benchmark curve:

Figure I.3.2.1.3: Benchmark curve for nitric acid plants based on data from 2016/17.[19]



However, due to the particular rules for the determination of the revised benchmarks for phase 4 of the EU ETS, the phase 4 benchmark was not determined by the new top-10%-average level, but by cutting the phase 3 benchmark by 24%. The new benchmark value is valid for the years 2021-25 in the EU ETS and amounts to 0.230 $tCO_{2e}/tHNO_3$.[20]

3.2.2 Product benchmark for adipic acid

Adipic Acid was fourth most emission intensive processes in the chemical industry in Europe at the time of preparation for phase 3 of the EU ETS. Five adipic acid plants emitted some 13 $MtCO_2$-equivalents per year in total. This limited number of installations posed challenges for the process of establishing a benchmark, because of confidentiality of data and little sense of using statistical methods. The European Chemical Industry Association Cefic carried out the benchmark study for adipic acid.

19 EU Commission: Update of benchmark values for the years 2021–2025 of phase 4 of the EU ETS, Benchmark curves and key parameters, 15 June 2021.

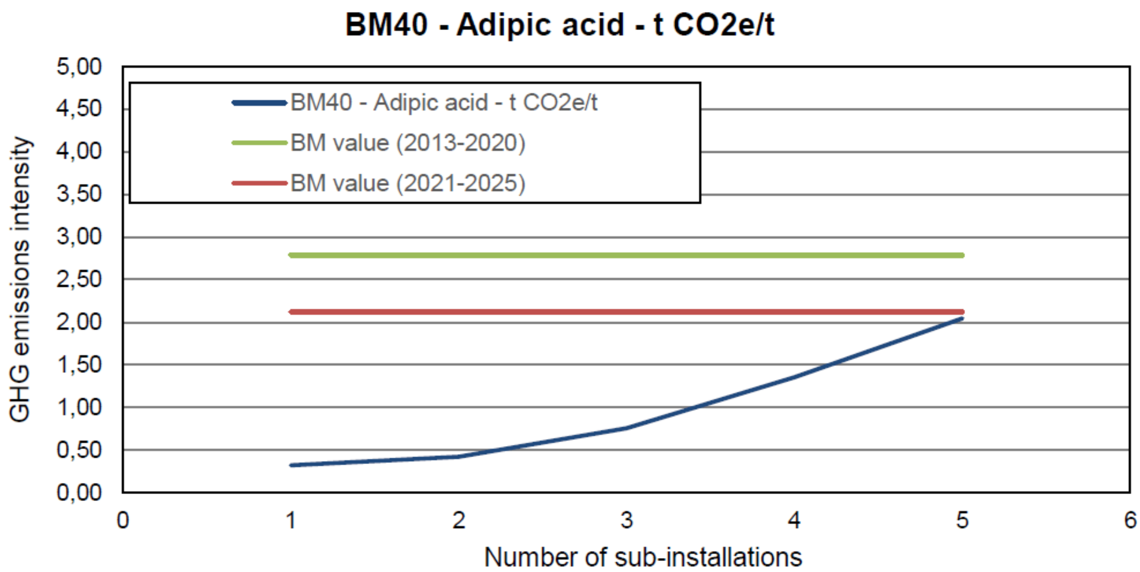
20 Commission Implementing Regulation of 12 March 2021 determining revised benchmark values for free allocation of emission allowances for the period from 2021 to 2025, see http://data.europa.eu/eli/reg_impl/2021/447/oj.

All installations were already equipped with some form of (end-of-pipe) abatement technologies or did partial recycling of N_2O in the manufacture of nitric acid, resulting in 90% or more N_2O abatement even before being included in the EU ETS. Detailed installation-level data were not made available by the industry association. The EU commission's consultants therefore turned to literature and compared the available information from the industry with the BREF documents[21] and emissions data from national inventories. This resulted in the proposal of 5.6 tCO_2-equivalents per tonne adipic acid, which corresponds to 94% abatement efficiency. Again, the EU Commission went even further and adopted a benchmark value of 2.79 allowances per ton of dry purified adipic acid for free allocation in phase 3 (2013-20).[22]

Revision for phase 4

With better data on GHG emissions from adipic acid plants obtained from reporting under the EU ETS, a benchmark curve helped to illustrate the emissions intensity in the years 2016/17:

Figure I.3.2.2.4: Benchmark curve for adipic acid plants based on data from 2016/17.[23]



According to those data, the average GHG emissions intensity of the top 10% most efficient installations was 0.32 tCO_{2e}/t adipic acid in 2016/17 – again significantly below the benchmark value. And like in the case for nitric acid described above, the maximum benchmark reduction of 24% was applied to determine the revised benchmark for the first half of phase 4: 2.12 tCO_{2e}/t adipic acid.

21 Cf. Chapter 1.

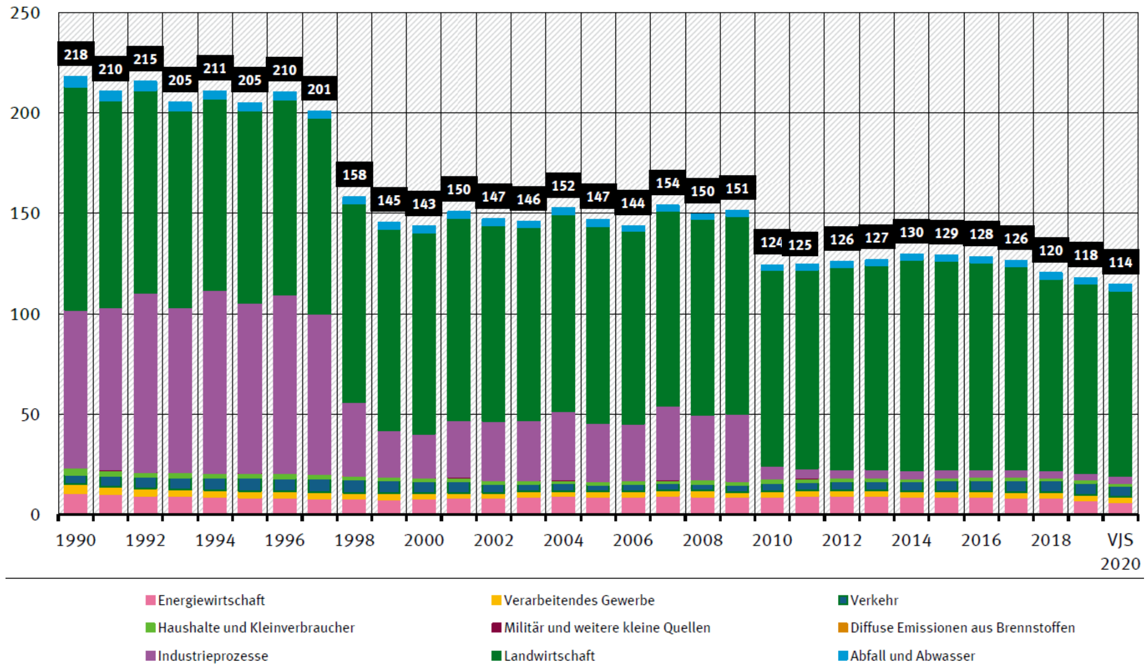
22 Cf. Table I.3.2.1.2.

23 EU Commission: Update of benchmark values for the years 2021-2025 of phase 4 of the EU ETS, Benchmark curves and key parameters, 15 June 2021.

4 Conclusions

From the description of policy instruments above, it becomes obvious that the incentives from the market-based mechanisms Joint Implementation (JI) and Emission Trading Scheme (ETS) had a significant impact on the abatement levels of nitric acid and adipic acid production. The effectiveness of environmental regulation (IPPC) cannot be conclusively evaluated since the deadlines for compliance with BAT emission levels happened to overlap with the introduction of the market-based mechanisms. In retrospect, it was the carbon market instruments that triggered significant N_2O abatement. This can be read from the development of N_2O emissions since 1990 in Germany:

Figure I.4.5: Nitrous oxide emissions by category in Germany[24]



The overall level of N_2O emissions is dominated by agricultural emissions (in green), whereas the downwards trajectory is solely explained by the industrial N_2O emissions (purple). The two significant steps down are the result of very effective abatement measures at the adipic acid plants in Germany. According to the federal environment agency, adipic acid production accounted for nearly one third of total N_2O emissions in Germany before 1997, while in 2017 it made up only 3%.

No matter whether with or without free allocation of allowances, putting a price on N_2O emissions leads to an incentive for plant operators to implement N_2O abatement – at least as long as the carbon price is higher than the respective costs of abatement. With a well-balanced free allocation scheme (applying product benchmarks), a carbon price offers a direct monetary reward for those installations that keep N_2O emissions below the benchmark level.

24 Source: Federal Environment Agency, https://www.umweltbundesamt.de/daten/klima/treibhausgas-emissionen-in-deutschland/distickstoffoxid-emissionen.

PART II: MRV requirements

1 Overview

The essence of MRV/What is MRV? Under Monitoring, Reporting and Verification (MRV) we understand the provisions and measures that are applied for emissions accounting including the steps to assure that this work follows standards and objectives. In the end, this helps provide transparency and ensure compliance of all internal and external processes within the N_2O emission mitigation.

Monitoring usually follows direct measurement or estimated quantification of emissions and emission reductions following rigorous guidance, such as the IPCC Guidelines or further provisions that have been defined for the EU ETS. Reporting entails documentation intended to instruct all interested parties on methodologies, assumptions, and emission data. Reporting is commenced from the standardized reporting templates, protocols and procedures that are used to feed into National GHG Inventory and other official documents. Verification, i.e., internal, or external, determines specific procedures or professional analysis used to verify the quality of the data and estimates. In a dedicated Annex to this report, there is a brief note on how ETS data is used in the national inventory reporting (⇒ ANNEX I-1a)

1.1 Regulatory framework

1.1.1 Central pieces of regulation

The MRV in the EU ETS is regulated by the following three central regulatory documents. The following text shortly describes the subject matter and the scope of each legislative act.

- **EU ETS Directive, EU ETD** (DIRECTIVE 2003/87/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL): This central Directive establishes the Emissions Trading in the EU (EU ETS), following the objective to promote cost-effective and economically efficient greenhouse gas emissions inside the EU. It helps implement the EU's contributions to avoid dangerous climate change and is aligned with the EU's international commitments (⇒ PART I). On MRV it lays down the central provisions and obligations within the scope of the EU ETS. As a directive it addresses member states that use further national legislative acts to implement its obligations. In Germany these include the Greenhouse Gas Emissions Trading Act (TEGH) and the Emissions Trading Ordinance (EHV), the latter further specifying aspects from the TEHG andMRV relevant issues.
- **EU Monitoring and Reporting Regulation, MRR** (COMMISSION IMPLEMENTING REGULATION (EU) 2018/2066 of 19 December 2018 on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council and amending Commission Regulation (EU) No 601/2012): This regulation is the central piece of legislation on monitoring and reporting, laying down specific rules for application of greenhouse gas accounting within the EU ETS. The regulation directly applies to national stakeholders throughout the EU.

- **EU Accreditation and Verification Regulation, AVR** (COMMISSION IMPLEMENTING REGULATION (EU) 2018/2067 of 19 December 2018 on the verification of data and on the ⇒accreditation [glossary] of verifiers pursuant to Directive 2003/87/EC of the European Parliament and of the Council): This regulation lays down specific provisions for the verification of ⇒emissions reports [glossary] and data relevant for the update of benchmarks as well the determination of free allocation for operators in the ETS. Moreover, it defines requirements for the accreditation and supervision of verifiers. The regulation directly applies to national stakeholders throughout the EU.

The Monitoring and Reporting Regulation refers in its provisions on the monitoring and reporting of emissions to "recognized standards" (**CEN, ISO, DIN standards, etc.**). These standards define how the measurement, sampling and analysis procedures must be implemented.

The MRR (Art. 31 para. 1c) allows the national competent authorities (in Germany: **Deutsche Emissionshandelsstelle**, DEHSt) to publish **lists of standard factors** to facilitate the monitoring and reporting for certain substances. These can be found on its website.

Moreover, the EU and Germany has published **guidance documents to facilitate the implementation** of tasks by operators and verifiers alike. With view to the basic monitoring and reporting obligations the following two DEHSt-publications are essential – the first helping clarify what is the scope of the emissions accounting, the latter helping define how to set up and execute the monitoring and reporting.

- **Scope of the Greenhouse Gas Emissions Trading Act (TEHG):** Information from the German Emissions Trading Authority (DEHSt).
- **Guidance on the preparation of monitoring plans and emissions reports** for stationary installations 4th trading period (2021-2030) of the European emissions trading scheme

1.1.2 Actors and levels in the rules making

The provisions in the EU ETS are the result of a complex interplay between institutions on different levels and of different origins.

The EU level: It is important to know that the EU is not a centralized rule making body but a framework for collaborative rule making in a multi-actor process that involves the European Commission, the European Parliament, and the Council of the EU (member states). In the evolution of ETS over time we see a stronger harmonization and centralization though. This is illustrated by the very fact that today both MRR and the AVR - the central MRV regulating documents – are EU regulations that directly apply to ETS operators and verifiers throughout the scheme. Until 2012 there were just Guidelines (MRG: Monitoring and Reporting Guidelines) where member states had to translate all provisions with a certain degree of discretion into concrete national rules.

The national level: Despite this harmonization, the national implementation reality still produces some noteworthy differences. Thus, for example, the concept of an "installation" is defined differently in various member states. Where in Germany "installation" refers to the narrowly defined permit for the single production facility in other countries like Belgium or the Netherlands the definition may encompass complete sites with multiple facilities. In Germany there are valuable

Guidance documents that transparently spell out the requirements from EU and national levels for operators. They thus provide a synthesis of the different rules ready for application.

Industry standards: On technical aspects the regulation often refers to accepted norms, defined by relevant standard organizations like the European Committee for Standardisation (CEN), International Organization for Standardization (ISO) or German Industry Standards (DIN).

Table II.1.1.2: Central pieces of MRV regulation and their origin

This table summarizes the major regulatory pieces for the MRV scheme and who defined it.		
(1) The EU sets the general regulatory framework while…		
The EU regulation		
• EU ETD (European Emissions Trading Directive)	(2) national regulation implements and further specifies the rules, both… **National regulation (Germany)**	
• EU MRR (Monitoring and Reporting Regulation) • EU AVR (Accreditation and Verification Regulation)	• TEHG (Greenhouse Gas Emissions Trading Act) • EHV (Emissions Trading Ordinance)	(3) referring to specific standards. **Standardization bodies**
• EU guidance documents and templates	• Regularly updated guidance documents, esp. “Guideline for the preparation of monitoring plans and emissions reports for stationary plants”) and an FAQ database	• DIN/EN/ISO Standards like EN14181
Source: FutureCamp		

1.1.3 Differences for JI and lessons learnt

Table II.1.1.3: The differences

The governance aspects below highlight relevant differences between the EU ETS and JI.	
Regulation	While the EU ETS as the common European emissions trading market is regulated by EU rules, JI was established under the Kyoto Protocol. Thus, JI is regulated by international rules under the UNFCCC process. JI methods and methodologies (e.g. monitoring and baseline methodologies or additionality tools etc.), modalities and procedures followed by and large the example of the Clean Development Mechanism (CDM). One distinction compared to the EU ETS is that for JI stand-alone methodologies defined the rules for different project types whereas in the EU ETS we see standardized rules for all emissions accounting, defined in a central volume of regulation. These standard rules apply to all projects of the same kind (JI track 2) or may be amended by national rules where tailor-made monitoring concepts for single projects are defined (track 1).
Actors in rules making	The JI rules are defined by international/intergovernmental regulatory bodies like the CDM executive board or the JISC (standard methodologies for track 2) or by national rules where national bodies (called: Domestic Focal Points) execute this work under track 1.
Source: FutureCamp	

Lessons learnt

The EU ETS implementation, through its regulatory framework, points to the available flexibilities that may be used for differentiation. For China, with its central and provincial level legislation, this may be used to define different ambition levels or allow certain parts of the country to experiment with special rules.

This is also in line with the flexibilities that were available under the JI regime (2008-2012) with a track 1 instrument. For an introduction into the JI mechanism and a brief distinction between the different tracks, please refer to ⇒ANNEX I-1b of this handbook.

1.2 Principles for MRV

1.2.1 On the value of MRV principles

In complex systems like the MRV system in an ETS the application of well understood and straightforward principles is important. They help implement and sustain a system in a way that its systematic objectives are met – especially when not every single eventuality is or can be regulated. As guardrails they thus give orientation also to the competent authority when fleshing out detailed rules or evaluating monitoring concepts for approval. In the EU ETS installation operators are supposed to follow key MRV principles as to facilitate a most effective procedure and assure accurate results within all processes. The discussed principles below stand at the centre of the EU ETS and help the monitoring system achieve its “designed purposes”.

1.2.2 Key MRV principles in the EU ETS

The MRR defines a set of major principles that are to be followed by operators when implementing their compliance work (MRR, Article 4). When looking at the detailed provisions set by the regulation for the implementation of the scheme it is evident that these principles are the basis of the implementation of the emissions accounting in the scheme.

- **Completeness (MRR, Article 5)** is a basic requirement, already when defining the emission sources and source streams of any installation that must be reported. As a rigorous requirement it requests the complete accounting of all such emissions for those installations that fall under the ETS – i.e., installations that have to report for defined activities and defined greenhouse gases (⇒monitoring scope [II.2.1]). In general, the individual monitoring plans (MP) for each site shall define adequate monitoring provisions that guarantee that all such emissions are effectively monitored and reported.
- **Consistency and comparability and transparency (MRR, Article 6)** define a set of principles that help assure a trustworthy accounting of emissions. This refers to the common standards and provisions that are followed by all when implementing the monitoring and reporting data. It also refers to the issue of sharing out of responsibilities amongst several parties in the MRV processes as to arrive at unbiased and well quality assured measurement results. Here the approval of the installation specific ⇒monitoring plan [II.2.3.1] by the competent authority further assures that there is no room for arbitrary definition of the monitoring and the reporting. Apart from sharing all relevant data with verifiers and authorities (thereby reducing time expenses on all sides), the transparency requirement is also an internal matter for the operator: Sensible allocation of responsibilities and information sharing among employees in charge of the monitoring and reporting will reduce the likelihood of errors, omissions and even eventual penalties.

- **Accuracy (MRR, Article 7)** must be assured without any systematic or knowing errors and biases from the installation operators' side. In general, the "highest achievable" accuracy shall be maintained, also referring to the acceptance that there may be limitations to this based on technical feasibility or the issue that unreasonable costs shall be avoided. The MRR establishes various degrees of accuracy dealing with different quantity of emissions of a particular installation, meaning that the operators of the installations with higher emissions are required to accomplish greater accuracy levels in comparison to the operators with lower emission levels. We discuss this further in the section on ⇒quality assurance [II.2.3.7].
- **Integrity of the methodology of the emissions report (MRR, Article 8)** is the basis for the operators to come up with a reporting that is robust (also in light of rigorous testing by the verifier) and ultimately free of material misstatements. In the first place this requires him to apply the monitoring plan in a rigorous way. This includes the maintenance of a solid data management and the balanced application of procedures for data evaluation and accounting. Integrity as a principle ultimately requires such due diligence that goes beyond the verifiers' auditing tasks. Still the verifiers' systematic review of the emissions reporting by independent certification is indispensable for meeting the integrity principle.
- **Continuous improvements (MRR, Article 9)** are an important characteristic of the ETS as a learning system. Learnings are reflected in the evolving rules of the system operators have to abide to once they are defined. And they are reflected in refined and adjusted monitoring processes, not least considering the lessons learnt from best available practice examples. A systematic element in the improvement of the monitoring is the improvement report. Here the operator must revisit and discuss existing or newly emerging potentials for improving the monitoring and reporting. This includes also corresponding recommendations received by the third-party verifier.
- **Conservativeness (MRR, Art. 3)** is a standard which requires data gaps to be closed. While this requirement is not included in the list of standard accounting principles, it still plays an important role. This will be revisited in the discussion of setting replacement/default values as part of the ⇒emissions calculation [II.2.3.5]

1.2.3 Differences for JI and lessons learnt

Table II.1.2.3: The differences

The aspects below highlight a couple of relevant differences between the EU ETS and JI.	
Conservativeness	In the JI context, conservativeness supersedes accuracy considerations. With the integrity of any offset regime being the basis to fungibility consideration of the certificates produced by these regimes, conservativeness here naturally functions as a safeguard. In an ETS some degree of uncertainty may be more easily accepted for the sake of feasibility and practicability.
Continuous improvements	In case of the CDM/JI offset practice a once approved monitoring plan as basis for a project applies irrespective of methodological improvements. In contrast, under the EU ETS, monitoring plans are regularly updated, reflecting the latest changes in the given requirements and monitoring rules.
Additionality	Additionality issues apply to offset regimes only. Additionality testing discusses whether a mitigation action was triggered or implemented due to the income from the offset regime – thus the emission reductions would not have happened/would not happen in the absence of that regime and the payments it channels (=baseline situation).

Integrity	While environmental integrity in the ETS case refers to robust emissions accounting, the issue for an offset regime is more complex. Here the discussion focusses much on a robust additionality testing in the first place. If additionality cannot be proven, integrity is at stake. Moreover, integrity may be lost where an offset regime produces so-called perverse incentives for over-production due to excessive income from the mitigation action, eventually resulting in overall higher emissions from a systems perspective. While for JI this issue was not the case in Germany and the EU, it still deserves some attention. We revisit this when wrapping up issues on ⇒ MRV and compliance [II.1.3.3]
Source: FutureCamp	

Lessons learnt

Principles for MRV are important and should be followed in any successful system. In the end good accounting is where a ton is actually treated and measured as a ton. Still with a set of partly conflicting principles in place, it deserves some attention where to put the focus on. All principles of accuracy, transparency and comparability have proper representation of reality at their core. This is different with conservativeness that is applied when accounting for ⇒data gaps during downtimes of the monitoring system [II.2.3.6]. It can be said that to some degree the application of the conservativeness principle in the emissions accounting of the EU ETS does systematically distort reality. The reason: There shall be no underreporting of emissions. Still, one could argue: In a well-managed system where the risk of gaming should be reduced by much such a safeguard to assure (individual) integrity may seem dispensable.

1.3 MRV and compliance

The so-called compliance cycle in the EU ETS is embedded in a broader MRV cycle that includes various steps. This section starts with an overview of these steps. It then shortly discusses the sharing of responsibilities in this balanced accounting system, followed by a comparison to the JI offset environment.

1.3.1 Elements in the MRV and compliance cycle

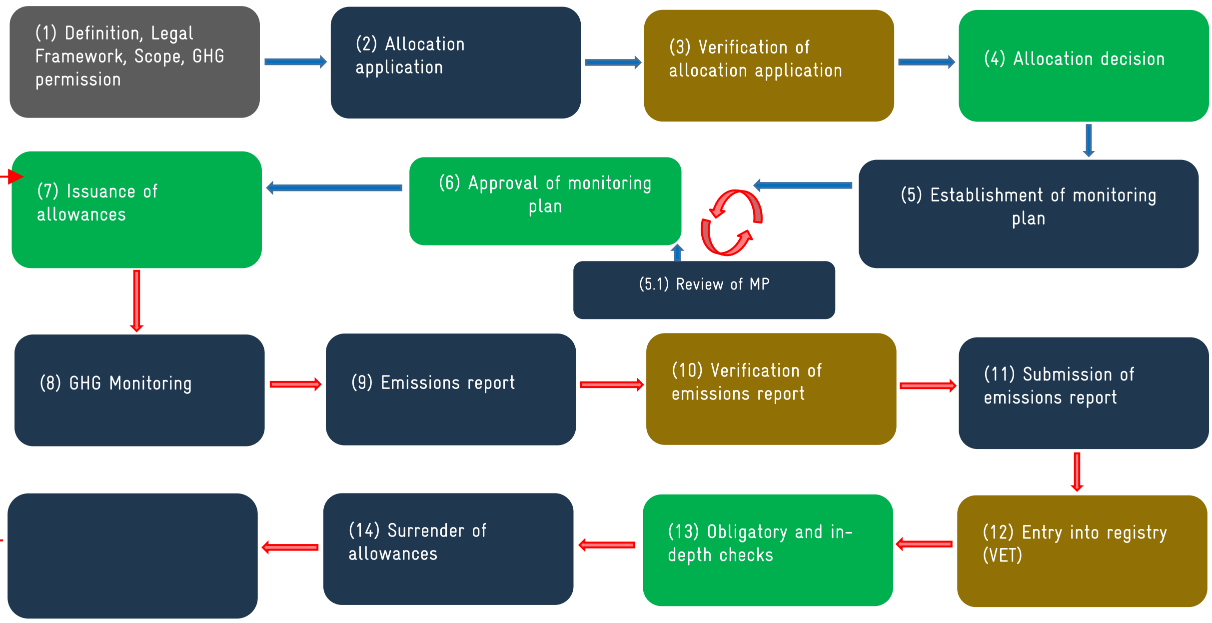
Setting aside the allocation related aspects, the MRV process consists of several important elements (in brackets: the number in the MRV cycle of table II.1.3.1).

- **Setting the rules (1)**: As shown in our introduction to the ⇒actors inrule making [II.1.1.2] the setting of rules in the EU ETS is an evolutionary multi-level task that also involves non-state actors.
- **Prepare and continuously improve monitoring concept (5/15):** Based on the rules the operator defines all critical information on how the emissions accounting shall be executed in the respective installation. This monitoring plan shall be adjusted once there are technical or methodological changes relevant for the emissions accounting – ideally before these changes are implemented. The operator discusses the situation on the implementation of improvements in dedicated ⇒improvement reports [II.3.2.1] that are handed in to the competent authority.
- **Approval of the monitoring plan (6)**: The plan is subject to approval by the competent authority. This applies also to any review of the plan so that arbitrary changes of monitoring methodologies are foreclosed.

Figure II.1.3.1: From allocation, definition of monitoring to the annual compliance cycle

This flowchart shows important steps in the MRV cycle in the EU ETS, including those that are implemented for emissions reporting each year (loop of red arrows). This latter process is also called the compliance cycle.

Legend: Grey: legislative body; Blue: operator; Green: competent authority; Orange: verifier



Source: FutureCamp

The subsequent steps form a continuous cycle that defines standard duties in the annual reporting of emissions.

- **Monitoring and reporting (8/9):** The monitoring plan helps the operator follow the monitoring and reporting agenda. In case the monitoring concept has changed within the reporting the operator may report also based on more than one approved monitoring plan.
- **Verification (10):** The verification process involves onsite audits and desk review activities. Once this review is finished the certification is completed.
- **Submission of Report (11):** The operator hands in the report to the competent authority.
- **Entry into registry (12):** The registry is independent from the reporting thus the emissions must be entered into that database (Verified Emissions Tables).
- **Checks by competent authority (13):** The competent authority checks and ultimately accepts emissions reports. It may also request adjustments or prescribe emissions.
- **Surrender of allowances (14):** With the surrender of allowances the main steps in the compliance cycle are accomplished.

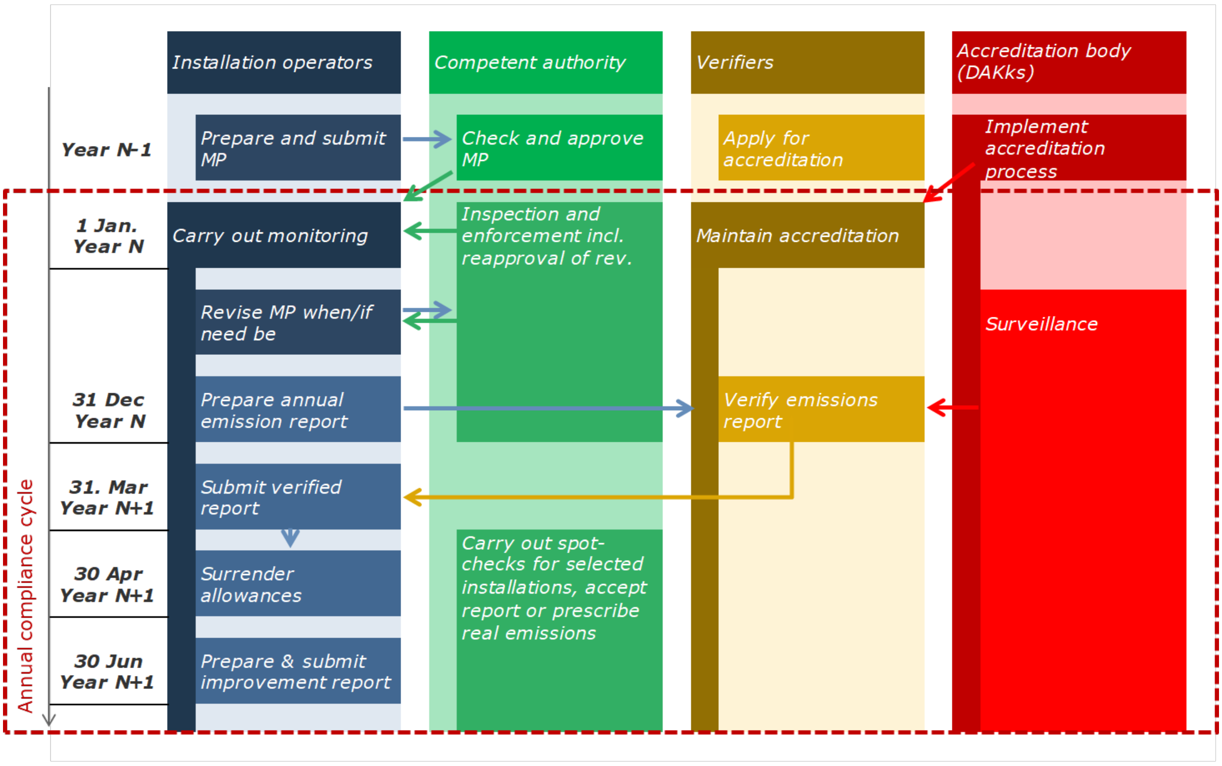
1.3.2 A system with shared out responsibilities and clear timelines

The EU ETS MRV and compliance cycle is built around the requirement that monitoring is always related to the calendar year. This comes with dedicated tasks, responsibilities and timelines that must be followed throughout the year and even before the monitoring actually starts. The allocation of these responsibilities lays the basis for a coherent and consistent reporting scheme that fulfils its objectives.

- **The operator:** The main responsibility of monitoring and the reporting is on the side of the operator. According to the EU ETD they operate and control the installation, thus are also in charge of implementation of the monitoring and reporting requirements. Operators therefore have the critical responsibilities to define and justify (by MRR standards) the monitoring concept in the form of a structured monitoring plan before start of the reporting (year): He is supposed to disclose the calculation and measurement of the monitoring method, explain whether and how MRR requirements were met as well as point out if the method deviates from the MRR. He submits the plan to the competent authority applying for its approval. Operators also have to submit a verified report of the monitored emissions three months after the end of the reporting year (§Section 5(1) TEHG). They are also liable and subject to penalties by the competent authority in case there are misstatements or more systematic mistakes in the finished reporting or underreporting of emissions. Moreover, it is the operator who hands in the allowances and is the main actor responsible for keeping the monitoring concept up to date. Figure II.1.3.2 lists the main tasks of the operator (left-hand side, column: operator) and shows how they are embedded in the actions of the other relevant actors: Arrows on the right pointing to and from other actors show how the operator interacts with them in the MRV cycle.

Figure II.1.3.2: The responsibilities of the main actors in MRV

This flowchart sums-up main interaction between the different actors in the MRV cycle of the EU ETS.
Note: The illustrated workflow includes just the main actions and is thus not comprehensive.



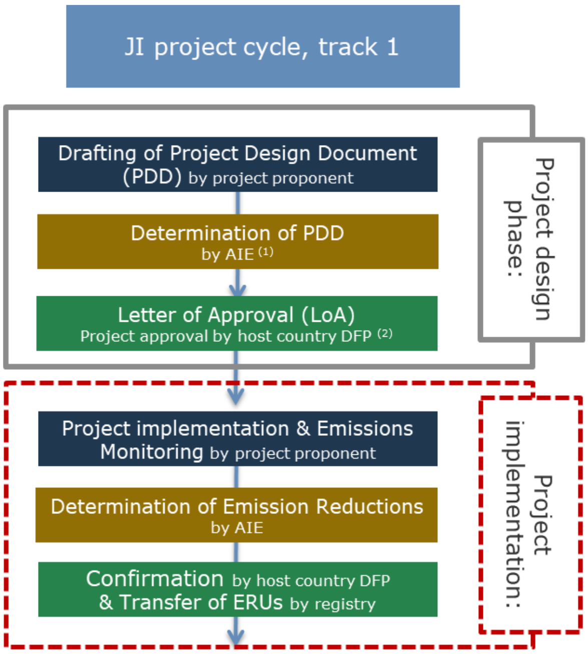
Source: FutureCamp, adjusted from flowchart in DEHSt M&R guidance document

- **The competent authority:** With its competence to check and approve monitoring plans and inspect the emissions reports, the competent authority has a critical responsibility in the scheme. In Germany there is just one central competent authority, the DEHSt. It is the main contact point for operators and delivers helpdesk functions. It also publishes central guidance documents and FAQ material with specific information on the monitoring and reporting requirements that must be followed by operators. Based on its position in the scheme, it has the best information and overview on the MRV implementation inside the scheme and thus also the capability to assure that the reporting meets high standards. If need be, it may also check the data on site (*§Section 20 (2) TEHG*). Operators have to provide data as a response to its requests. Should an operator neglect to submit an emissions report or does not comply to the MRR in his report and fails to correct that or the report is not (positively) verified in accordance with the A&V Regulation, the DEHSt may also apply its own estimate of emissions using a conservative method (Article 70(1) MRR).
- **The verifier:** Emissions reports must be verified by an independent third-party verifier that is accredited for executing this task (*§Section 21 and §Section 5(2) TEHG). This follows a* sector accreditation of the verifier for activities in group 9: production of adipic and of nitric acid (Art. 35 and ANNEX I AVR). The rigorous verification process reduces the reporting risks by the operator. Through executing an independent, professional and systematic scrutiny of the monitoring processes and data the verifiers help correct mistakes but also in general improve the quality of the reporting. He checks whether there are deviations from the approved monitoring plan (i.e. non-conformities) or further issues of non-compliance with the MRR rules. Apart from checking data in a desk review he usually also goes onsite inspecting the installations during his auditing. Therefore, he is able to gain a good understanding of the implementation of the monitoring on the ground. Ultimately the verification report as part of the emissions reporting also facilitates the review work by the competent authority through systematic and transparent documentation of relevant test items. The certification of the emissions report by the verifier is necessary for being accepted by the competent authority.
- **The accreditation body:** In order to assure the high quality of verification there is a dedicated institution with a dedicated competency. In Germany the accreditation body Deutsche Akkreditierungsstelle (DAkks) supervises the work of the verifiers and makes sure through a well based accreditation process that only qualified verifiers execute work in the ETS. Main provisions for this task are defined in chapter 4 (on Accreditation) of the AVR.

1.3.3 Differences for JI and lessons learnt

Table II.1.3.3: The differences

<table>
<tr><th colspan="2">The aspects below refer to main differences regarding the elements in the compliance cycle and the distribution of responsibilities.</th></tr>
<tr><td>While the offset project cycle is very similar to the cycle in the ETS case, i.e.
• The sharing out of responsibilities involves again all four components or actors, i.e. project proponents, the competent authority (here: DFP), independent verifiers (here: AIE) and an accreditation body (not shown in the flowchart).
• Process-wise, it also includes the preparation of the project design document (PDD – equivalent to the monitoring plan in the ETS) by the project proponent as a starting point. Again, an approval by the competent authority is required before implementation starts.
• The implementation phase with independent audits and the final review by the competent authority again follows the ETS example.

Still there are main differences:
• In contrast to the ETS case, the approval of the monitoring plan already involves a review of the PDD by an auditor.
• In the JI case there is also no strict annual compliance cycle by calendar year.
• Moreover, as the monitoring concept in JI track 1 is often tailor-made, the scrutiny by the competent authority both of the concept and confirmation of determined emission reductions is more important.</td><td>
</td></tr>
<tr><td><u>Peculiarity:</u> Baseline period /measurement as part of the cycle</td><td>For offsets, the required monitoring does not simply focus on the monitoring of actual emissions levels when the mitigation technology is implemented. It may also involve a determination of a real or hypothetical baseline against which emission reductions are calculated. As this baseline determination may involve gaming problems for ⟹<u>environmental integrity [II.1.2]</u> may emerge.

Especially based on experience from the early days of CDM, two drivers for perverse incentives for overproduction of adipic acid were identified: Firstly, in projects, assumed baseline abatement levels were too low or even nil – thus the mitigation volume ready for crediting was inflated. Secondly, the income from Certified Emission Reductions (CERs) due to high offset prices even exceeded the value of adipic acid itself, thus incentivizing an expansion of production while the value of the product became secondary.[25]</td></tr>
<tr><td colspan="2">[1)] AIE: Accredited Independent Entity (see glossary) [2)] DFP: Designated Focal Point (see glossary)
Source: FutureCamp (2022/2016)</td></tr>
</table>

25 For a concise description of this, please refer to CAR (2020): Adipic Acid Production Protocol, Appendix B (Evaluation of Leakage Potential).

Lessons learnt

Sticks or carrots? The ETS, by putting a price on carbon, follows the polluter pays principle whereas the JI and any other offset regime rewards operators for voluntary action. This is more than a philosophical question. The different functionality may also produce very different results. Applying the polluter-pays principle is more straightforward and in the long run the more sustainable solution.
Need to calibrate the income stream? JI/offset regimes are incentive regimes. In case the economic benefit is (too) large, this may create perverse incentives. This was visible from the case of offsets from adipic acid production. Thus, it seems reasonable for an offset regime to consider capping the income stream from certification/the offset price or align it with real transaction and implementation cost for the offset project.

2 Monitoring requirements

2.1 Monitoring scope

The issue of what is to be monitored is quintessential. In classical CDM terms this is defined by the ⇒project boundary [glossary]. Also, in any ETS this aspect relates to the question of what – in terms of emissions and proof of these – falls within the scope of the instrument and thus under its monitoring requirements.

2.1.1 N_2O and CO_2 emissions from the activities

For the EU ETS, the ETD in its Annex I defines the general activities and ⇒greenhouse gases [glossary] that fall under its scope. Independent of the installed production capacity both nitric acid and adipic acid production facilities must thus report their emissions under the ETS since 2013. For both activities N_2O emissions and CO_2 emissions are included. In Germany these requirements are mirrored in German Greenhouse Gas Emissions Trading Act (TEHG, part 2 of its Annex 1, activity no. 23 and 24 each). Moreover, as the German law does not extend the scope of the ETS also to caprolactam production activities, these facilities in Germany do not fall under the EU ETS.

The MRR further lays down the scope of monitoring on the level of ⇒emissions sources [glossary] and ⇒source streams [glossary] for these ETS covered activities: in its Annex IV (section 16) it states that the scope includes “all sources emitting N_2O from production processes, including where N_2O emissions from production are channelled through any abatement equipment”. Here differentiations are notable: Due to the high concentrations of N_2O in the off gas of adipic and caprolactam production facilities, for these activities also venting and emissions from measurement equipment have to be considered, while N_2O from combustion of fuels is generally not subject to monitoring for any of the three activities. As table II.2.2.a shows, there are notable differentiations.

Table II.2.1.1: EU ETS: Monitoring of N_2O emissions from the following sources

Due to the high concentrations of N_2O in the off gas of adipic acid and caprolactam production, emissions from measurement equipment have to be considered, while N_2O from combustion of fuels is generally not subject to monitoring for any of the three activities.	
For the activities of…	N_2O emissions from the following sources are to be monitored:
Nitric acid production	- Oxidation of ammonia - NO_x/N_2O abatement units
Adipic acid/caprolactam production	- Oxidation reaction - Any direct process venting - Emission control equipment
Source : MRR, Annex IV, section 16.	

2.1.2 General parameters for emissions accounting

On the single plants level, the EU ETS refers to so called ⇒installations [glossary]. The monitoring boundaries here are usually defined by the so-called greenhouse gas (GHG) emissions permit. In Germany each installation has such a permit either due to being subject to the pre-existing local emissions control regime OR due to a dedicated, separate emissions permit that may be granted in cases where this aforementioned permit does not define a clear delineation of the boundaries of an installation (TEHG, §4, 1 and 4).

In line with the ⇒completeness [II.1.2] principle, all emissions from any of the elements covered by the GHG permit of the installation – including its core components necessary for the operation and the ancillary equipment. Thus, CO_2 emission e.g. from use of auxiliary electricity generators – even if it is just from annual testing only – must be accounted for as well. There is no minimum threshold and thus emissions from all sources must be monitored without exception.

The data to be monitored is contingent on the monitoring methodology that is used for the emissions accounting. It differs for calculation-based approaches and measurement approaches respectively. This information is discussed in the subsequent section on ⇒measurement methods [II.2.2] and the section on the ⇒monitoring plan [II.2.3.1] that lays down all relevant information for the monitoring.

For ⇒continuous emissions measuring systems [II.2.2.2] as used for N_2O accounting, the scope of the missions accounting is further defined by a clear definition of operation time that is subject to monitoring and reporting of emissions. Since 2017 there is a standardized ⇒definition of operating hours that are subject to emissions accounting [II.2.3.4], applying to all industrial emitters that have to report their N_2O emissions under the EU ETS. This so-called "Standardised Federal Practice for Monitoring Emissions" defines two criteria that must be monitored along the other emissions raw data. Hourly values to which none of these two criteria apply are to be set to "0" in the reporting of emissions and thus remain outside the scope of the ⇒emissions calculation [II.2.3.5].

2.1.3 On the transfer of source streams

Chemical sites are typically integrated sites where both primary raw materials and downstream products based on the primary raw materials are produced. This means that there are not only links along the value chain, but also corresponding potentials for integrating different plants. This applies to exchange of both heat and waste gases including for further use of these source streams.

Thus, the transfer of gases incl. N_2O at such chemical sites is a common process. On the issue of how to deal with the transfer of N_2O between installations the regulation has been refined over time. There is a new article 50 in the MRR that is valid from 2021 onwards. Systematically these provisions are in line with those for transfer of CO_2.

Table II.2.1.4: Monitoring/accounting of transferred N_2O

Art. 50 of the current MRR contains specific provisions that largely follow the German implementation practice before 2021. The requirements to use Continuous Emissions Measurement Systems (CEMS) for monitoring further clarify the treatment.		
SITUATION / ASPECT	Transfer by an ETS facility to another ETS facility	Transfer by an ETS facility to another ETS facility
Measurement	• Transferred volume shall be directly measured (⇒CEMS [II.2.2.2])	
	• Both transferring and receiving may measure quantities while reporting (if need be, conservatively) aligned values (MRR, Art. 48 (3)	
Emissions accounting	• Not accounted as emission at facility where it originates but at receiving installation • Same monitoring methodologies apply for receiving installation (as if N_2O was generated there	• Default case: counted as emissions to installation where they originate • Exception to this: Operator demonstrates to the CA that N_2O emissions are destroyed in receiving installation using suitable abatement equipment.
Source: MRR, Art. 50, Art. 48 (2).		

The objectives followed with regulating the transfer are to assure the integrity of the accounting. At the same time the provisions are ready to facilitate the innovative use of N_2O in products outside of the facility, where the emissions are bound permanently OR the destruction of these emissions in facilities outside of the installation they originate from. Mitigation measures and use cases that are in line with the description given above emerged in Germany already in the form JI projects before 2012/the inclusion of the chemical activities under the EU ETS.

2.1.4 Further monitoring items: activity data for free allocation

In case free allocation applies (as is the situation in the EU ETS) there is also further activity data that must be monitored. This data is used for ⇒benchmarking [I.3.2] and the annual adjustment of the free allocation volume.

Production data: The logic with the annual adjustment is to align the free allocation with the real production volume. Thus, adipic and nitric acid facilities in the EU ETS also report their production data on an annual basis.

Consumption of heat: From the production of nitric acid usually large volumes of heat are produced and exported. It is noteworthy that this cross-boundary use of heat is generally not eligible for free allocation. This is due to the fact that this heat is already accounted for in the product-specific benchmark that applies to the free allocation for nitric acid production.

2.1.5 Differences compared to JI and lessons learnt

The free allocation issue is a prominent feature of an ETS. It does not apply to an offset instrument. Still, it has some striking similarities to the baseline setting under an offset instrument (“baseline & credit”). We shortly discuss the differences between offset project baselines and benchmarks in an ETS.

Table II.1.2.3: The differences

Major differences between the EU ETS and JI relate to the issue of baseline campaigns	
Baseline campaigns	In an ETS there is no need for the monitoring of baseline campaigns. This also limits the room for gaming. The issue of gaming is very important in the offset case where a project-specific baseline is used – based on installation-specific emission intensities. Please also note the discussion of the gaming issue in offsets in the section on the compliance cycle [III.1.1.3]. But note: in that case, free allocation applies under an ETS general emission, and production information is also required for the setting of standard benchmarks. This work can follow complex data gatherings – as is the case in the EU ETS.

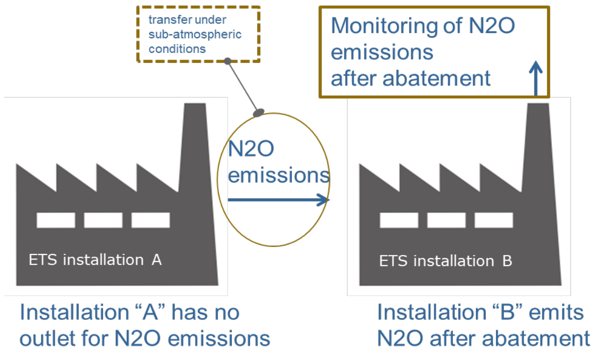
Lessons learnt

The baseline or benchmark determination can be a costly challenge. An alternative to reduce red tape and lower accounting risks would be for both ETS and offset instruments to simply refer to best practice benchmarks (BAT). The co-benefit here would always be a stronger incentive for incumbent, less efficient installations to go for emissions abatements.

On this, please also note the later discussion on ⇒mitigation technologies [III.] where one strategic option for mitigation is the decommissioning of old facilities and the investment into new, more efficient production facilities.

Another important take is the relevance of having easy, accessible, and trustworthy information on the boundaries of an installation. In Germany this information is usually available from standard emissions permits that contain such data in the required quality.

CASE STUDY: There are two installations that fall under the ETS. Plant A (nitric acid plant or adipic acid plant) has no emissions outlet. It transfers its process gas including the unabated emissions to nitric acid plant B. Installation B has installed mitigation technology. It emits the residual N_2O that is both from its own processes and the emissions it receives from installation A after mitigation.



Moreover, on transfer of emissions in between installations, the ETS case teaches some valuable lessons:

Firstly, there can be cases that require a more flexible treatment of the monitoring scope. In certain cases, the competent authority may thus shift from strict adherence to the concept of emissions boundaries defined by an installation (as clarified in its permit) to a more flexible and adjusted treatment. In the example (see box on the right), only emissions from installation B after abatement need to be monitored according to the defined standards.

Secondly, and at the same time, the competent authority needs to make sure that there is no systematic leakage in reported emissions, and that the quality standards (integrity) for emissions accounting remain high. Here he may consider safeguards and controls for rigorous monitoring of the transferred volumes, e.g., by requiring a transfer under sub-atmospheric pressure conditions (here pipeline leaks would not result in emissions to the atmosphere).

2.2 Measurement methods and equipment used

As discussed below, the selection of an adequate measurement method for the emissions accounting is important. We discuss these methods in detail and lay down the specific requirements from the regulation and their rationale. On the concrete equipment we refer to German/EU experience with list of certified equipment ready for application.

2.2.1 Emissions accounting methods

Emissions can be determined based on three distinct major accounting methods. Figure II.2.2.1 presents them in an overview table.

Standard calculation-based approaches: Here emissions are simply calculated based on calculation factors and throughput or input volumes.

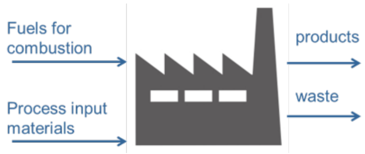
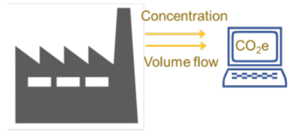
- In case of process emissions this is an emissions factor for the carbon content in a fossil-based input or production quantity and the oxidation rate. In Germany for the oxidation factor there a standard value of "1" is to be applied (Annex 2, Part 1 TEHG). This simplifies the calculation and follows a conservative assumption that all carbon content is oxidized.
- In case of emission from combustion processes of a material stream, the plant operator determines the quantity of fuel used and multiplies this by the lower heating value as well as the corresponding emission factor for the fossil fuel (Art. 24 MVO).

Mass balance approach: Here emissions are calculated based as the delta between the carbon content in the input and the output of a production process. The calculation approach uses two elements in its equation, multiplying the results from a concentration measurement by the measured volume flow (Art. 25 MVO).

Continuous Emissions Measurement Systems: From a competent authority's point of view today the continuous emissions monitoring systems (CEMS) is on equal footing with the other calculation-based approaches in the EU ETS. This is the result of technology improvements and gained confidence in the quality of the measurement results. It furthermore reflects a shift in relevance due to the inclusion of N_2O emissions from chemical production sites into the scheme in 2012.

Still data from 2018 clearly shows that measurement-based monitoring approaches in the EU ETS cover just 56 Mt CO_{2e} or <4% of verified emissions [LITERATURE: Art.21 2019 Report, p. 51f]. In that year, 67 installations used this method for N_2O emissions accounting in the EU as a whole. In Germany this figure stands at 11 emitting chemical industry facilities in 2020 [LITERATURE: VET Report 2020].

Table II.2.2.1: Emissions measurement approaches

In principle for emissions accounting there are different approaches available. The MRR distinguished between two general calculation based approaches and the application of Continuous Measurement Systems (CEMS)		
Calculation-based approaches		- Direct measurement approach c) continuous monitoring
a) Standard approach	b) Mass balance approach	
		
Emissions = input or output streams * emissions factors * oxidation factor	$Emissions = f * (\sum C_{Input} - \sum C_{Output})$	Emissions = Concentration * Volume flow

In general, the MRR grants some discretion to plant operators when selecting the monitoring methodology they intend to apply to each source stream, always under the condition that the required accuracy levels can be met. This is different for N_2O emissions accounting in the EU ETS as well for all activities discussed in this handbook. Here specific monitoring methodologies apply (MRR, Annex IV, section 16:B1, pursuant to Art. 20(2)), prescribing the application of continuous emissions monitoring.

For CO_2 measurements in general CEMS is still the exception in the EU ETS. For adipic acid and nitric acid this is even more so as CO_2 emissions in these plants plays only a minor role and the accounting via calculation-based approaches generates adequate results and is more reasonable.

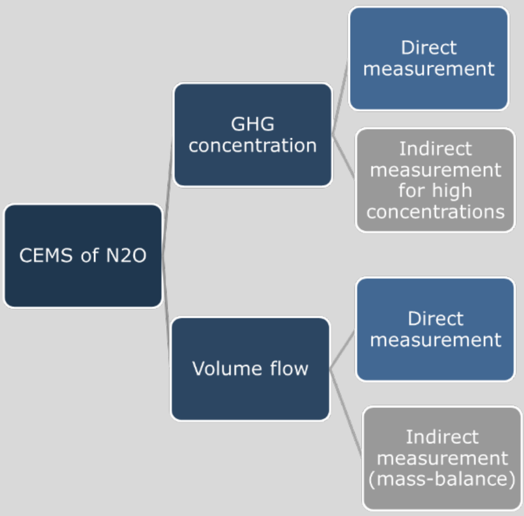
2.2.2 Continuous emissions measurement for N_2O emissions

For emissions determination via measurement-based methodologies, the MRR defines different options (Art. 43) in general. These include the combination of direct and indirect determination methods on the basis of hourly values and the hourly determination of emission loads.
Direct measurements are independent of the stoichiometric relationships. Thus, for N_2O accounting in principle they provide the best measurement results. While the MRR thus generally requires CEMS for the monitoring of N_2O emissions this comes with certain distinctions, highlighted in table below. It shows that the CEMS is actually a mixture of direct and indirect measurement methods.

Table II.2.2.2: EU ETS: CEMS for monitoring of N_2O emissions

According to the MRR at adipic and caprolactam production facilities CEMS shall be applied only for abated emissions while non-abated emissions shall be calculated.	
For the activities of...	N_2O emissions are to be monitored via:
Nitric acid production	• CEMS in general
Adipic acid/caprolactam production	• CEMS for accounting of abated emissions • Calculation-based (mass balance) method for unabated emissions

There are different options for utilization of CEMS



Concentration measurement

- For N_2O concentration measurement in CEMS, direct measurement is standard.
- In case of high concentrations though, emissions may be determined indirectly through the measurement of the concentration of other the gas components in the flue gas also.

Volume flow control

- For VTG at nitric acid plants in general applying a mass balance method is most appropriate and also the standard rule: see MRR, article 43(5)(a) and Annex IV, section 16 (B.3)
- A waste gas flow determination via a mass balance approach may also be technically impossible under certain plant engineering conditions. This applies, for example, to nitric acid plants with several interlinked production lines and a multitude of stacks/outlets. Here the homogeneity of the gas flow in the complete plant is not given.
- There are cases where a VTG measurement through mass balancing is technically not feasible, e.g., at multiline production plants with single stack or interlinked production lines where the homogeneity of the gas flow is not given. Here a deviation from the regulation is permissible. Any such deviations are laid down and justified in the ⇒ monitoring plan [II.2.3.1].

Source : MRR, Annex IV, section 16, subsection B.1

2.2.3 Recommended equipment in Germany

In general, before selecting any equipment it could be economically interesting to consider whether an integration into other existing CEMS is possible, e.g., there could be existing equipment for local pollutants like SO_2 or CO.

On suitable measuring and evaluation equipment including those for emissions and local pollutants control, the German Umweltbundesamt (UBA) publishes regularly updated lists. The separate lists for concentration and volume flow measurement instruments gather the published announcements from the Federal Gazette. The UBA also keeps a registry of all certificates for the measuring equipment online.

More detailed information on the equipment, such as type designation, measuring objects, manufacturer and further information on the field of application, can be found in the respective announcements themselves, available also on the UBA website.

Table II.2.2.3: Suitability tested equipment for CEMS

UBA lists ("Suitability tested continuous emission measuring equipment. The date of the individual measuring objects indicates the status of the last update. The QAL1 website online contains certificates for all equipment that was certified according to EN15267 since 2009.			
Excerpt/examples taken from the instrument list on measurements of "Nitrous oxide (N_2O), (laughing gas, also nitrogen oxide) – Last update: 11.08.2021"			
Type/in-strument	Manufacturer	Published in, date, no., page	Notes
MCS 100 FT for O2, CO, SO2, NO, NO2, HCl, HF, CH4, CO_2, H2O, N_2O, NH3 and total carbon content	SICK AG, Reute	[...]	[...]
		BAnz AT, 17.07.2018, B9, p. 9	III., 25. notification: – digital interface – new software version
		BAnz AT, 03.05.2021, B9, p. 18	III., 53. notification: – new material for soldering base
ULTRAMAT 23-7MB2338 for CO, CO_2 und N_2O	Siemens AG, Karlsruhe	[...]	[...]
		BAnz AT, 01.08.2016, B11, p. 9	V., 28. notification: – new software version

Excerpt/examples taken from the instrument list on measurements of "Exhaust gas volume flow – Last update: 11.08.2021"

Type/in-strument	Manufac-turer	Published in, date, no., page	Notes	QAL1 Certificate, example for FMD 09 (Dr. Födisch)
FMD 09 for exhaust gas volume flow	Dr. Födisch Um-welt-mess-tech-nik AG, Mark-ranstädt	[...]	[...]	
		BAnz AT, 05.03.2013, B10, p. 19	V., 25. notification: – new software version	
FLOWSIC 100 for exhaust gas velocity	Sick Enginee-ring GmbH, Ot-ten-dorf-Okrilla	BAnz AT, 05.08.2021, B5, p. 17	IV., 43. notification: new software version	

Source: UBA, adapted/translated by FutureCamp; the updated instrument lists can be downloaded at: http://www.umweltbundesamt.de/themen/luft/messenbeobachtenueberwachen/anerkannte-messgeraete-messverfahren, the QAL1 certificates can be found at: www.qal1.de

2.2.4 Differences compared to JI and lessons learnt

Both JI methodologies and the EU provisions for implementation of N_2O accounting make use of similar approaches. Due to the stoichiometric nature of N_2O emissions they make CEMS the standard case.

The EU implementation of N_2O measurements is ruled by differentiated provisions. They account for the fact that certain types of measurements are better than others. Through some flexibility they also acknowledge that different plant constellations may also favour or hinder certain measurement methods. Therefore the principle should be to define rules that accommodate different plant constellations while meeting general quality standards for good monitoring. The subsequent chapter further describes features in the monitoring process that help realize both objectives.

It could be of value for operators to have a list of approved equipment for CEMS monitoring in place. In German the UBA keeps such a database with all relevant information for interested stakeholders. We revisit this aspect when discussing the general ⇒quality assurance [II.2.3.7].

2.3 Monitoring processes

Each installation under the EU ETS has a monitoring plan. In this section we state the general contents and structure of this essential document that defines the monitoring of emissions. We briefly discuss the issue of updates and reviews as well. All contents of the following subsections are reflected in the monitoring plan.

We start with elementary aspects where the monitoring plan defines the basis for emissions accounting, i.e., firstly the tier requirements that help define adjusted uncertainty requirements for installations in their monitoring and reporting of emissions. Secondly the essential information on methods and instruments used when measuring relevant emissions data.

In the following subsections with a focus on accounting we show: Prior to accounting of emissions from CEMS, there is a standard determination step that helps determine whether an hour and its measured emissions are subject to monitoring and reporting or not. Calculation formulae only apply for hourly values that meet the respective criteria. For hours that are invalid or data gaps there are special rules that apply to the emissions accounting.

The last couple subsections focus on quality assurance. They discuss the requirements and present the procedures that facilitate a solid implementation of the measurements in line with the ⇒key MRV principles for emissions accounting [II.1.2.2].

2.3.1 Approved monitoring plan for transparency ab initio

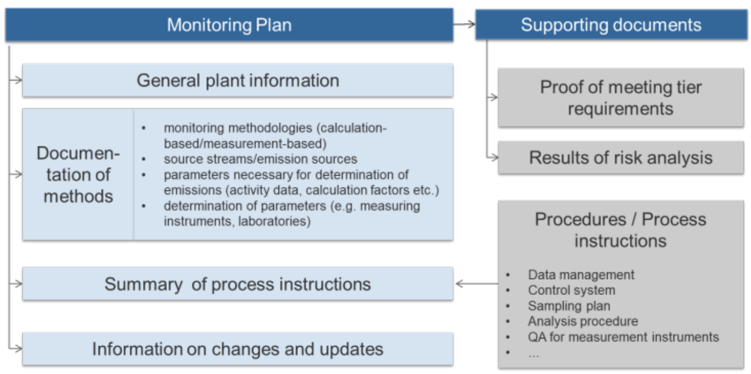
The monitoring plan defines the monitoring protocol that is to be followed when accounting for the emission and preparing the emissions reporting. It describes the methods for determining emissions for each emission source within the scope of reporting. It helps establish and implement a MRV concept that is in line with the main ⇒MRV principles [II.1.2.2] including completeness, consistency, accuracy etc. set by the MRR. For that objective it specifies the provisions from the regulation and guidance tailored to the plant situation in a non-arbitrary way.

Table II.2.3.1a: Monitoring plan: Its structure and components

A monitoring plan contains certain components. In bold fonts are standard elements in any monitoring plan for adipic and nitric acid production sites. Other elements may be included according to the monitoring situation.

GENERAL INFORMATION

Operator	• General address data • Main contact person (phone/email)
Authorized representative This information refers to the contact point	• Address data • Main contact (phone/ email)



Summary Presents central emissions data from the differ-rent monitoring parts.	• Categorization of installation • Emissions total (anticipated) • Executed activity under the ETS • CO_2 emissions: before deduction of transferred volume, transferred CO_2 stream • N_2O emissions: including from transfer, transferred emissions volume
Installation Describes activities carried out, emission sources and source streams, demonstrating absence of data gaps or double counting of emissions.	• Contact
	• Production (installation) • Production parts (by installation component). • If descriptions are more complex, they may be included in a general ATTACHMENT to the monitoring plan. It may also contain/embed the mandatory
	➔ Flowchart Usually this is a simple diagram of the emission sources, source streams, sampling points and metering equipment. It facilitates the description of the above and any other parts of the installation that are relevant for the monitoring methodology including data flow activities and control activities.

MONITORING EQUIPMENT

Measurement instruments	Here relevant information on the measurement equipment that is used for the monitoring of parameters used to calculate emissions must be described. This includes the type, the (description of) method, the ID of the instrument, its measurement range and typical measurement range as well as measurement frequency. On quality assurance a description must be given including specific information like calibration (type) including interval and identified uncertainty of the instrument. ATTACHMENT: If there is no standard uncertainty by the manufacturer, the operator should attach an individual uncertainty calculation for the instrument.
Analysis methods	For other kind of CO_2 source streams where no CEMS or other standard values are applied, concentration values may be derived from analysis. The applied process is documented in an analysis plan, attached to the monitoring plan.
Laboratories	In case analysis methods are applied it is also important to document that the laboratories employed are accredited to ISO/IEC 17025 or that equivalence to this accreditation is guaranteed (via ATTACHMENT of the equivalency certificate).

MONITORING METHODS				
Report component CO_2	➔ CO_2 measurement	➔ Fuel HW	➔ Material stream	➔ Mass balance
Report component N_2O	➔ N_2O measurement Here the measurement method is to be described for each source and the instrument(s) is/are to be ticked from the established list of equipment (see monitoring equipment above). In case a standard method (e.g., mass balance for volume flow in nitric acid production plants) cannot be applied, this has to be justified. In general, the aspect of homogeneity of the source stream is to be discussed. The template also contains a standard list of typical types "downtimes". ➔ N_2O transfer The template contains data fields on how transferred emissions are monitored; the importing/exporting installation's ID; whether it is subject to emissions trading and whether or how emissions are measured in the other installation as well.			
Data management	Here the general dataflow is described from the collection of raw data, the data processing and transfer and the data storage up to eventual determination of the emissions values. This description is important as it helps in understanding and discussing where processing error risks exist in the data. We further outline the essence of data control when presenting the respective ⇒process instruction [II.2.3.3]. It includes results from the risk analysis that are to be ATTACHED to the monitoring plan as well. They explain where residual risks must be accounted for when considering the correctness of the monitored/calculated emissions. A dataflow diagram is also ATTACHED for easy understanding of how data is processed and stored. Results of a more complex risk analysis are often attached to the monitoring plan.			
Source: Annex I, MRR.				

The size of a monitoring plan may vary by complexity of the installation. For a simple case (with no relevant CO_2 emissions) it may be around 35 pages long, for complex multi-line installation it may even reach 200 pages or more. Important parts of the documents for ongoing monitoring may lay outside the plan. We discuss some of these ⇒process instructions [II.2.3.8] below.

Changes in the monitoring plan: Changes may become necessary due to new rules, if verifiers have advised their application or if an evaluation by the operator in line with the ⇒improvement principle [I.1.2] shows that they would be appropriate and proportionate. There are well defined process requirements for the ⇒reporting of changes in the monitoring concept [II.3.2.1] including the submission of a regular improvement report.

2.3.2 Uncertainty requirements and the use of tiers

The control over uncertainty is an essential aspect in the accounting system of the EU ETS. It also stands at the centre of the monitoring concept and is a major aspect when the authority is considering the approval of the monitoring plan.

The so-called tiers in the EU ETS refer to accuracy requirements for emission accounting of all methods of emissions determination. In general, the regulation applies the following rule: the higher the emissions of an installation or relevant source stream, the higher the accuracy requirement.

For N_2O emissions the MRR defines three levels, the highest asking for an accuracy of ≥95%. This is different from the corresponding requirements for CO_2 accounting where there is also a tier 4 threshold of 2.5%.

Table II.2.3.2a: Monitoring plan: Applying tier thresholds for N_2O emission accounting via CEMS

Based on the tier concept, installations are treated differently. The following table shows the defined three levels for N_2O emission accounting that shall be met – with tier 1 as the minimum requirement.			
TIER LEVEL / ASPECT	Tier 1	Tier 2	Tier 3
UNC thresholds	10%	7.5%	5%
Where it applies	Minimum tier, can only be applied in case higher tier is technically impossible or involves disproportionate costs	Minimum standard requirement for installation with emissions <50.000 t CO_2 e/a (category A)	Standard requirement for installation with emissions >50.000 t CO_2 e/a (category B/C)
Source: MRR, Art. 19(4), Annex VIII, para 1 and 2.			

In principle operators who measure N_2O emissions must comply with the tier 1 uncertainty level. A deviation from tier levels 2 and 3 is possible if the operator can prove that meeting the requirement involves disproportionate costs or there is a technical infeasibility involved.

2.3.3 Monitoring methods and equipment used

The monitoring plan shall include essential information on measurement equipment.

Table 2.3.3: Monitoring plan: Requested information on measurement equipment

The monitoring plan contains data on defined parameters of monitoring equipment. This table lists these and gives brief explanations on the requested contents.	
Measurement of what?	Instrument for mass control (calculation method) or CEMS
Internal equipment number location	The equipment number shall also be included in the flow diagram (ATTACHMENT) and the location will help easy identification during onsite visits.
Responsibility	It shall be clear who is in charge of managing the equipment (readings, quality control).
Fabrication type and measurement method	The instrument type and the applied measurement method shall be clear, especially in case there is no standard application.
Measurement range, typical working range and frequency	Here the range as indicated by the manufacturer and according to typical operating conditions shall be indicated. For CEMS, frequency of the measurements shall be indicated (e.g., 1/second).
On process instruction	Description of the applied process for quality control, showing "how" measuring equipment is calibrated and quality controlled at regular intervals with regard to risks in data collection and data management.

Regarding quality assurance the monitoring plan includes further data points as shown in ⇒Table II.2.3.7c below.

2.3.4 Definition of operating hours which are subject to accounting

As outlined in our discussion of the ⇒parameters for emissions accounting [II.2.1.2] the MRR requires complete reporting of all emissions throughout the reporting year. For accounting by CEMS the competent authority requests the strict application of transparent criteria to evaluate whether an operating hour is subject to monitoring or not. Since 2017 a dedicated document prepared by DEHSt sums up the information in form of a concise guidance document for operators [⇒

LITERATURE: KEMS-Arbeitshilfe]. The table below outlines the two criteria including available options:

Table II.2.3.4: Monitoring plan: Definition of operation hours subject to emissions accounting

As soon as one of the following two criteria is met for any individual hour, its values must be recorded by the Continuous Emissions Measurement System (CEMS) and processed for the annual emissions reporting.	
Criterion 1	Criterion 2
The instantaneous value of the CEMS for the volumetric flow reaches the threshold value of 4 % of the „operating point" or of the annual average of the exhaust gas volume flow.	At least one of the following other operating measurements or condition signalling that identifies the combustion of fuels: • Exhaust gas temperature exceeds 60°C. • Exhaust gas oxygen concentration falls below 20.5% by volume • Reactor operation active • SCR catalyst active (ammonia or urea added, or similar).
Source: DEHSt (2018) KEMS-Arbeitshilfe.	

2.3.5 General calculation of emissions and corroboration

Emissions values are calculated on an hourly basis. For the determination, the following equations apply.

Table 2.3.4: Calculations and formulae

Annex IV of the MRR lays out the standard activity-specific monitoring methodologies related to the determination of N_2O emissions from nitric acid, adipic acid and caprolactam production. It defines the following formulae and provisions for the emissions determination.	
STEP	Formulae and relevant text in the MRR (italic text is taken from the MRR)
Annual N_2O emissions Equation B.1: (ANNEX VIII, section 3)	The operator shall monitor emissions of N_2O from nitric acid production using continuous emissions measurement. The operator shall monitor emissions of N_2O from adipic acid, caprolactam [...] production using a measurement-based methodology for abated emissions and a calculation-based method (based on a mass balance methodology) for temporary occurrences of unabated emissions. $GHG\ Em_{total}\ [t] = \sum_{i=1}^{HoursOp} GHG\ conc_{hourly,i} \cdot V_{hourly,i} \cdot 10^{-6} [t/g]$
Hourly N_2O emissions Equation B.2: (ANNEX VIII, section 3)	$GHG\ Em_{average}\ [kg/h] = \frac{GHG\ Em_{total}}{HoursOp} \cdot 10^3 [kg/t]$ The operator shall determine hourly N_2O concentrations in the flue gas from each emission source using a measurement-based methodology at a representative point, after the NO_x /N_2O abatement equipment, where abatement is used.
Determina-tion of flue gas flow Equation B.3: (ANNEX IV) Mass balance (fall-back ap	To determine the flue gas flow in N_2O emissions monitoring, the operator shall either use a mass balance methodology or continuous flow measurements. For nitric acid production, the operator shall apply the mass balance methodology – unless it is technically not feasible. In that case and upon approval by the competent authority, the operator shall apply an alternative method, including a mass balance methodology based on significant parameters such as ammonia input load, or determination of flow by continuous emissions flow measurement.

	$V_{flue\ gas\ flow}\ [Nm^3/h] = V_{air} * (1 - O_{2,\ air}) / (1 - O_{2,\ flue\ gas})$ Where: V_{air} = Total input air flow in Nm^3/h at standard conditions; $O_{2,\ air}$ = Volume fraction of O_2 in dry air [= 0,2095]; $O_{2,\ flue\ gas}$ = Volume fraction of O_2 in the flue gas.

The V_{air} shall be calculated as the sum of all air flows entering the nitric acid production unit.

$$V_{air} = V_{prim} + V_{sec} + V_{seal}$$

Where:

V_{prim} = Primary input air flow in Nm^3/h at standard conditions;

V_{sec} = Secondary input air flow in Nm^3/h at standard conditions;

V_{seal} = Seal input air flow in Nm^3/h at standard conditions.

The operator shall determine V_{prim} by continuous flow measurement before the mixing with ammonia takes place. The operator shall determine V sec by continuous flow measurement, including where the measurement is before the heat recovery unit. For V_{seal} the operator shall consider the purged airflow within the nitric acid production process.

[Facilitation:] For input air streams accounting for cumulatively less than 2.5% of the total air flow, the competent authority may accept estimation methods for the determination of that air flow rate proposed by the operator based on industry best practices.

The operator shall provide evidence through measurements under normal operating conditions that the flue gas flow measured is sufficiently homogeneous to allow for the proposed measurement method. Where non-homogeneous flow is confirmed through these measurements, the operator shall take that into account when determining appropriate monitoring methods and when calculating the uncertainty in the N_2O emissions.

The operator shall adjust all measurements to a dry gas basis and report them consistently. To correct humidity in the input air flow the formula is to amended, based on the average molar water content in the input air flow, adding a the following factor to the equation: $(1 - H_2O_{,\ input\ air\ flow})$.

Determination of average annual concentration Equation 2a (Annex IV)	$GHG\ conc_{average}\ [g/Nm^3] = \frac{GHG\ Em_{total}}{\sum_{i=1}^{HoursOp} V_{hourly,i}} \cdot 10^6 [g/t]$
Source: MRR.	

In the calculations only values need to be considered that are obtained during regular plant operating hours (for the criteria see ⇒Table II.2.3.4).

Corroboration of values: The MRR (art. 46) requires the operator to corroborate emissions that are determination by use of CEMS. This requirement though does not apply for N_2O emissions accounting at nitric acid production facilities. Corroboration would usually be done through applying a standard or mass balance methodology (see ⇒section II.2.2.1). For this recalculation no ⇒tier requirements [II.2.3.2] must be met.

2.3.6 On downtimes, data gaps and replacement values

As the emissions reporting is to be complete (see MRR, art. 5), data gaps have to be filled. For measurement approaches the following criteria apply.

Table 2.3.6a: Data gaps and data replacement for continuously measured values

<table>
<tr><th colspan="4">The MRR (art. 45 para 2) requests: "Where a valid hour of data cannot be provided for one or more parameters of the measurement-based methodology due to the equipment being out of control, out of range or out of operation, the operator shall determine values for substituting each missing hour of data." Below we discuss the definition of valid data or data gaps and their treatment.</th></tr>
<tr><td></td><td colspan="2">Analysis of different cases</td><td>Applying default values?</td></tr>
<tr><td>Case 1</td><td colspan="2">Hourly values are lacking
• they are e.g., outside of the measurement range,
• there is a failure of the measurement,
• there is no data recording,</td><td rowspan="3">For any such values or data gaps replacement values have to be applied.</td></tr>
<tr><td>Case 2</td><td colspan="2">Hourly values are invalid in this sense that
• the minimum availability of 80% of single values for the full hour (2 seconds data) is not given (MRR, art. 44 para 2).
The CEMS shall indicates a failure for that hourly value.</td></tr>
<tr><td rowspan="2">Case 3</td><td rowspan="2">Hourly values exceed the calibration range.
Here the CEMS does register the values. The problem: These values have a higher but unspecified uncertainty than values within the valid calibration range.</td><td>& UNC threshold for the source stream is not met for the monitoring year</td></tr>
<tr><td>& UNC threshold for the source stream is met for the monitoring year</td><td>No, the recorded values are accepted.</td></tr>
<tr><td colspan="4">Source: MRR.</td></tr>
</table>

<u>Please note:</u> Not automatically protocolled in the CEMS are **eventual drifts of measurements**. If these remain undetected by quality control measures for a too long period of time (i.e., they cannot be corrected through recalibration) these values are also invalid and must be replaced.

On the replacement values themselves, there is the principle in the EU ETS that those values should be "conservative." Per MRR (art. 3 para 19) this "means that a set of assumptions is defined in order to ensure that no underestimation of annual emissions […] occurs." The standard procedures to do this is by adding a suitable "safety margin" to the calculated replacement value. This follows the spirit of the MRR, where a 95% confidence level is also used for uncertainty assessment.

The calculation of replacement values can either be automatically implemented in the CEMS or must be applied through further processing of CEMS data e.g., in excel sheets. The table below shows the standard case for an installation with constant parameters in the flue gas.

Table 2.3.6b: The calculation of replacement values

<table>
<tr><th colspan="2">The MRR (art. 45 para 3) requests: "Where a valid hour or shorter reference period of data cannot be provided for a parameter directly measured as concentration, the operator shall calculate a substitution value as the sum of an average concentration and twice the standard deviation associated with that average".</th></tr>
<tr><td>Substitution value for missing data
Equation B.1: (ANNEX VIII, section 5)</td><td>$C^*_{subst} = \overline{C} + 2\sigma c\_$
Where:
$\overline{C}$ = the arithmetic mean of the concentration of the specific parameter over the whole reporting period or, where specific circumstances applied when data loss occurred, an appropriate period reflecting the specific circumstances;
$\sigma_{C\_}$ = the best estimate of the standard deviation of the concentration of the specific parameter over the whole reporting or, where specific circumstances applied when data loss occurred, an appropriate period reflecting the specific circumstances.</td></tr>
<tr><td colspan="2">Source: MRR.</td></tr>
</table>

Please note: If the parameters in the flue gas are volatile (e.g., there are gradually higher N_2O concentrations over time due to aging of the secondary catalyst) the modified rules apply: Here both the arithmetic mean and the standard deviation are calculated based on the 120 preceding valid hourly values measured before that event.

For indirectly measured values (as it may be the case for volume flow), a mass balance approach may also be applied when calculating the surrogate values (MRR, art. 45 para 4).

2.3.7 Quality assurance (general)

In Germany, routine measurements are carried out especially for air, noise and water to ensure that the quality of environmental media is controlled and that measures to safeguard and improve quality can be assessed.

For CEMS, the quality assurance is to confirm that the applied system is fit for purpose (measurement with the defined accuracy), has been correctly installed, and is regularly calibrated and tested for proper functionality. In the following we outline the levels of the quality assurance that is to be applied at each installation on a regular basis.

The main provisions for the quality assurance are laid out in the norm EN14181 (Stationary source emissions - Quality assurance of automated measuring systems (AMS)) and several supporting norms, presented in the subsequent table.

Table II.2.3.7a: Overview of quality assurance standards

Overview of quality assurance standard for emissions accounting through CEMS.		
1) Central standards referred to in the MRR	**2) Further standards that the above refer to/help implement the above**	**3) Important standards for determination of flue gas flow**
CEN, EN 14181:2014–Stationary source emissions - Quality assurance of automated measuring systems ✓ Calibration according to EN 14181	EN ISO 14956 – Air quality – Evaluation of the suitability of the measurement procedure by comparison with a required measurement uncertainty ✓ Defining QAL 1 procedure as required per EN 14181	EN ISO 16911 Stationary source emissions – Manual and automatic determination of velocity and volume flow rate in ducts Part 1: Manual in reference method Part 2: Automated measuring system
EN 15259 – Air quality - Measurement of emissions from stationary sources - Requirements for measurement sections and for the measurement task, measurement plan and measurement report ✓ Selection of the measuring point (or the measuring cross-section) according to DIN EN 15259 ✓ Maintaining an accurate and reliable emissions testing	EN 15267-3 – Air quality – certification of automated measuring systems – Part 3: Performance criteria and test procedures for automated measuring systems for monitoring emissions from stationary sources ✓ Is an application of EN ISO 14956, ✓ Defines CEMS testing procedures and the determination of measurement uncertainties	**4) Further helpful standards** EN 14790: Stationary source emissions – Determination of the water vapour in ducts ✓ Moisture measurement under EN 14181 EN ISO 21258 – Stationary source emissions – Determination of the mass concentration of dinitrogen monoxide ✓ Nitrous oxide for MRR Annex IV, Section 16, subsection B.2 EN 14789 – Stationary source emissions – Determination of volume concentration of oxygen (O2) – Reference method – Paramagnetism ✓ Oxygen measurement under EN 14181 for MRR Annex IV, Section 16, subsection B.4 and Art. 43(5) (a):

Source: MRR Guidance document No. 7, section 3.1, adapted by FutureCamp.

The base level is the **suitability testing (or QAL1)** of measuring equipment. It is defined that only suitability-tested measuring and data acquisition equipment is approved in Europe for application in CEMS. Operators may look for accepted equipment and respective certificates on an official website (https://qal1.de/de/index.htm).

The equipment then must also be properly applied at the installation and tested for **adequate functionality (QAL2)**. This is done by an accredited testing lab once after installation and then repeated at least every three years. Apart from confirming that the equipment has been properly installed (meeting measurement specific requirements at the point of measurement), QAL2 is also used to calibrate the equipment through (at least 15) comparative measurements by use of mobile standard reference measurement methods. The derived calibration parameters help convert raw values [mA] into physical measurement values. They are then fed into the CEMS by the operator/CEMS service provider. The QAL2 testing also checks the uncertainty of the CEMS and provides the relevant values from the variability (standard deviation between CEMS and reference measurements) to calculate the uncertainty for measurements during competent authority operation.

Apart from the QAL2 there is also an **Annual Surveillance Test (AST)** that must be implemented. This is a simplified testing, consisting of at least 5 comparative measurements, to confirm the validity of the QAL2 parameters on an annual basis. If the test fails, the QAL2 has to be repeated. The German competent authority has also laid down further criteria prompting a repetition of the QAL2 test in its guidance document.

The third level of quality assurance is a **routing quality testing (QAL3)**. Here the operator applies separate or combined testing of (a) a potential drift and (b) maintained precision of the measurements (test of reference point and zero point; 7.2/ EN1481) Requirements for routine QAL3 tests applies for both concentration and volume flow measurements. If the tests uncover deviations there may be readjustments, maintenance, and repairs of the equipment or even a complete recalibration.

The table below sums up the essential information on the quality assurance for CEMS.

Table 2.3.7b: Overview of quality assurance

The quality assurance follows the requirements of the norm EN 14181. It has three levels.			
QAL LEVEL / ASPECT	QAL1	QAL2	QAL3
The objective	Preliminary uncertainty assessment, demonstrating the general suitability of the instrument	Proper installation, calibration (QAL2) and testing of results through Annual Surveillance Test (AST)	Ongoing quality control of CEMS, proving its stability through zero and span checks
When and how often?	Before installation of CEMS, could be repeated (simplified test) e.g., in case of change of software	Calibration once after installation, every 5 years (per EN14181) / every 3 years (defined by German CA) / in case of failed annual AST validation.	Continuously during operation
Who is in charge?	Responsibility: plant operators/ manufacturers; Implementation: accredited third party auditors.	Testing and calibration laboratories (accredited per EN ISO/IEC 17025 or equivalent)	Plant operators
Result/ certificate	QAL1 certificate confirms uncertainty in defined measurement range	QAL report technical compliance with the MRR requirements	Control charts (CUSUM) approve cards approve
Source: MRR Guidance document No. 7, section 3.3, adapted by FutureCamp.			

The calibration and quality assurance of measuring equipment in regular intervals shall limit the risks associated with data collection and data management. The monitoring plan contains essential information on this.

Table 2.3.7c: Monitoring plan: Information on the quality assurance of measurement instruments

In the monitoring plan for each measurement the following quality assurance information shall be laid down.	
Type of quality assurance	The applicable quality assurance is to be indicated (calibration (=instruments subject to national legal metrological control) or conformity assessments). For other types of QA methods than these two, a detailed explanation of this procedure is to be given.
Measurement uncertainty type and value	The type of permissible service error limits must be specified. E.g., for conformity assessed meters this can be either the permissible service error OR the calibration error. The uncertainty value shall also be indicated.
Frequency of calibration	For standard calibration (instruments are subject to national legal metrological control) OR conformity assessments; the frequency shall be indicated. For standard QAL2 of N_2O measurement equipment in Germany this is e.g., "every 3 years".

2.3.8 Process instructions

MRR Article 12 and its Annex I refer to procedures. They must be established, documented, and maintained by the plant operator outside the monitoring plan. The most important process instructions are presented in the table below.

Table 2.3.8: Written internal process instructions

The following central process instructions (usually documented outside of the monitoring plan) shall generally be made available to the verifier. The competent authority will receive the written documents upon request.	
Data flow and data management	This process instruction regulates the data flow to ensure legally compliant reporting. • Gives an overview of the installation and its emission sources and describes the data flow (from primary data collection to the annual reports). Its flow diagram is to be ATTACHED as a separate document to the monitoring plan. • Describes the process steps in the ⇒emissions calculation incl. formulae and data used [II.2.3.5]. It furthermore shows when and which electronic processing and storage systems or manual input methods apply. Here it outlines the treatment of downtimes and values if these are not in line with standard rules including the calculation of default values. • Outlines the uncertainty calculation.
Data control system	Risks in monitoring and reporting can and should be mitigated by use of control activities. This process instruction describes this quality assurance for the measurement equipment relevant to the monitoring plan (per MRR art. 59 para 3a). The risk assessment is an integral part of the data control system: It systematically discusses each step in the data flow (see also data flow above) with a categorization of the probability that error will occur and respective impacts on the emission calculation – before and after implementation of control activities. The results of this analysis are ATTACHED to the monitoring plan.
Quality assurance of measurement equipment	This process instruction amends the data control procedure above by a detailed description of the quality assurance that is to be applied for each instrument. It thus lays down specific control measures (per MRR art. 59 para 3 b-g) applied or supervised by the responsible staff in the plant. It gathers relevant information on the measurement instruments, the inspection plans that apply and further data on the routine frequency of the inspection including their documentation (e.g. in the form of standard test sheets).
Corroboration of emissions	In general, as a plausibility check-up for CEMS a corroboration of emissions values with calculated values is necessary (46 MRR). This requirement though does not apply for N_2O emissions accounting at nitric acid production facilities. This written procedure lays down the steps for the corroborating calculation to validate the ⇒general calculation of emissions [II.2.3.5].

The monitoring plan itself typically just contains minimum data points from the instructions, i.e. a clear reference (title including a standard abbreviation) and information on the used storage for keeping relevant records and information and the IT system used. It must further be made clear who has the responsibilities for implementation of the process instruction at hand and for the data generated or generated or managed by the procedure. The procedure itself shall be briefly described incl. the standards (norms) to be applied, allowing all actors to easily understand its characteristic features and its work processes.

2.3.9 Troubleshooting

By means of QAL3 and other quality control measures, the emissions accounting is permanently quality checked. In case drifts are detected only late there is a need to understand the reason for this (so that control measures can be improved). And the drift itself must be understood: Which part of the equipment has a problem? Can the equipment be repaired? Is a recalibration of the equipment required to correct the data?

Moreover, to learn about potential events in the past that may have led to the failure/lasting drift of an instrument, a transparent daily events protocol may be helpful. Here the operator and staff will note down operating conditions (such as start-ups, etc.) or the implementation of service measures and further routine measures implemented at the instruments for each day.

There may also be instances where the regulation requires rather prompt notification, a kind of heads-up to the competent authority regarding the non-functioning of the CEMS and sorting out ways how to deal with that.

2.3.10 Differences compared to JI and lessons learnt

As JI ended in 2012, several improvements in the accounting that were implemented based on the gains in experience during the last ten years are only visible in the EU ETS implementation.

Table II.2.2.3: The differences

The aspects below highlight a couple of relevant differences between the EU ETS and JI.	
Standard replacement values	In offset case (along BImSchG) there can be further differentiation of replacement values, to be applied (by operating status: e.g. for start-up). In fact, the competent authority in Germany (DEHSt) also accepted more adjusted values for special conditions und the EU ETS.
Operating hour	Since 2017 there is a standard definition of operating hours in the EU ETS. It certainly improved the transparency and reduced risks from arbitrary implementation.
Valid hours	The valid hour is defined by a two-thirds criterion (i.e. 66%) under the EN14181 and in the offset case. In the EU ETS this criterion is stricter (80%). In case an installation has many downtimes this rule could make quite a large difference – especially when we also look at the question of how many downtimes in total are acceptable for a decent monitoring.
Tier system	In the offset context, there is no tier system. Thus, whereas in the EU ETS low emitting installations are treated differently compared to large emitters (with lower requirements regarding permissible uncertainty in place), the offset instrument treats all installations alike.
Quality assurance of volumetric flow	Experience showed that drifts, incorrect operation, e.g., due to contamination of meters, were detected too late. As a result, incorrect determination of the exhaust gas volumetric flow over longer periods and corresponding conservative closure of data gaps were necessary. This is especially the case where the quality control of the volumetric flow is inadequate. The proper consideration of the EN 16911 should be considered.

Lessons learnt

Both for emissions monitoring under JI and the EU ETS, the definition of monitoring plans/project design documents before implementation of the accounting is a standard.

In order to reduce costs for emissions monitoring/equipment, it seems reasonable to consider the application of a tier system like the one in the EU ETS. Here smaller emitters are relieved from some of the burden without compromising on the all-over accuracy of emissions accounting in the scheme.

As discussed in our section on troubleshooting having a protocol of daily events seems helpful to allow for larger transparency and better understanding of the conditions and the performance of the measurements.

When concentration of emissions varies across a wide range (e.g. abated vs. unabated emissions), it could be reasonable to install two systems that allows for the integrated monitoring with two different measurement ranges.

The risk analysis as part of the data control system (including its results documented as part of the monitoring plan) is a valuable instrument to identify, evaluate and to minimize inherent risks through focused implementation of control activities. It also discusses what the residual risks are after such risk mitigation through additional controls, i.e., describing where in the dataflow errors may still occur, or cannot be completely eliminated. Based on this discussion there is good understanding of whether the risks for monitoring and reporting (mistakes and deviations from approved methodologies) are acceptable or whether further improvements should be realized. It is important to note that as monitoring problems are usually discovered over time the risk analysis is an iterative work and an important aspect of ⇒improvement reports [II.3.2.1]

3 Reporting requirements

3.1 Reporting cycle and format

3.1.1 Timeline for reporting

There are several targets for the reporting timeline. Excluding the issue of free allocation and benchmark report to the authorities,[26] the following dates and reporting deliverables are of relevance. Reporting requirements include:

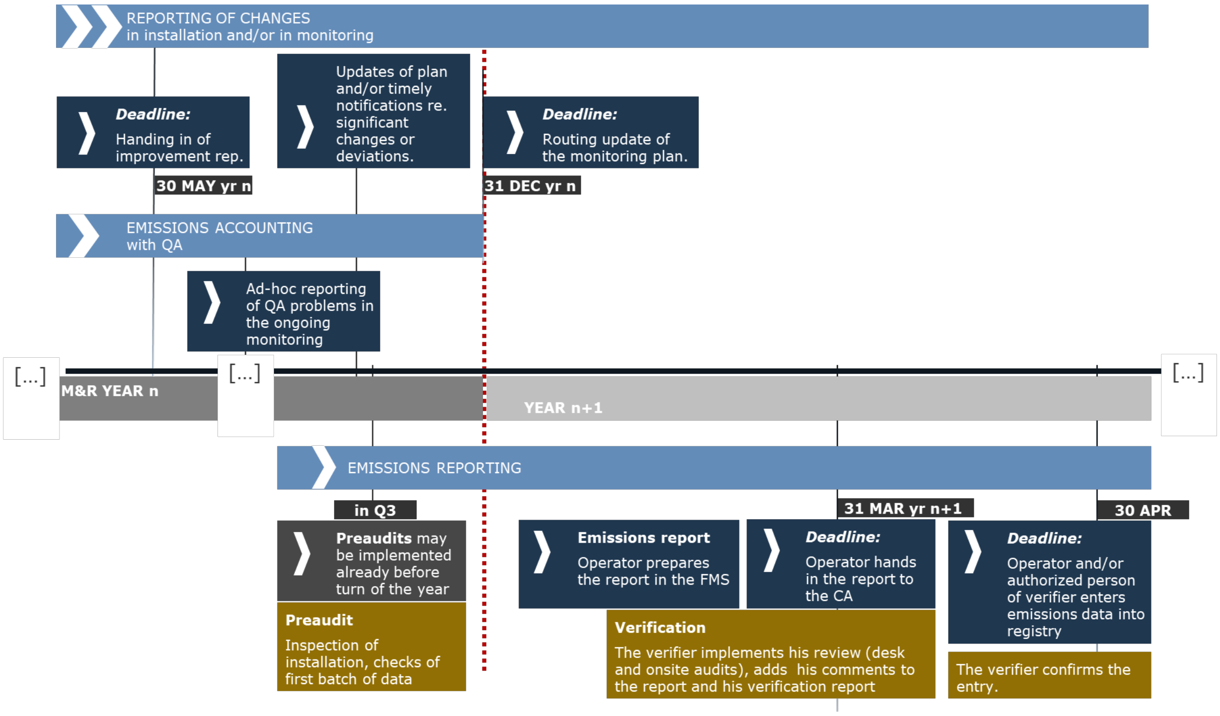
1) Ongoing and regular reporting on changes in the monitoring concept – which is done throughout the year as changes are planned and/or implemented in monitoring.
2) Ongoing ad-hoc reporting requirement on special events that are to be flagged to the competent authority during the monitoring year – this is to be done as matters arise during ongoing monitoring of data in the reporting year.
3) Reporting of emissions through preparation of an emissions report and the entry of emissions into the registry - which is done in the first quarter of the year following the reporting year; preaudits with the auditors may be implemented further in the reporting year.

The following table presents an ideal-typical timeline of the three kinds of reporting throughout the year.

26 For reporting of allocation and benchmarking data, also steam consumption and generation plays a role. The scope reporting thus goes beyond the parameters for emissions monitoring.

Table II.3.1: Timeline for reporting

This table presents the three levels of reporting by operators in the EU ETS. We further explain these in detail in sections II.3.2.



Source: FutureCamp.

3.1.2 Use of digital templates/data management system

In the EU ETS, we see an integrated application of standard formats/templates where reports are compiled based on the import of monitoring plans. This facilitates the preparation of a concise and transparent documentation of the report. On contents please also refer also to the structure and contents of the ⇒approved monitoring plan [II.2.3.1].

3.2 Reporting obligations to competent authority

In general, the reporting obligation lies with the operator, as indicated in the monitoring plan. The reporting obligation applies for the full reporting year and is born by the party that operates the installation at the time when the report is prepared. Thus, in case the operator changes (e.g., due to M&A or change in company name) the competent authority has to be informed without undue delay.

3.2.1 Reporting duties regarding the monitoring concept

There is a reporting duty that relates to the update of the monitoring plan. Updates may apply due to changes or regular review and discussion of the established ⇒monitoring plan [II.2.3.1] in light of possible and/or requested improvements. The duties on that follow a defined concept:

- First, there is the definition of non-significant changes. These include changes that serve to correct what was previously described in the monitoring plan. Such changes should be collected and reported together with the next significant change, at least on an annual basis (end of year).
- Second, significant changes in the installation or the monitoring are treated differently: Here, there shall be an immediate notification of the competent authority and prompt review of the monitoring plan. In any of these two cases the operator hands in a revised monitoring plan for re-approval.
- Third, a category of changes which do not have to be reported are routing meter changes or changes in the internal process instructions. These changes still need to be documented by the operator and this documentation must be shared with the auditor within the annual audits. The competent authority sees it only upon specific request in individual cases.

Table 3.2.1a: Monitoring plan: Significant and non-significant changes

This table lists significant and non-significant changes that must be notified to the competent authority.	
Significant changes (per MRR, Art. 15) prompt immediate review of the monitoring plan. If possible, the competent authority shall be notified of the changes in advance of their implementation.	Non-significant changes (as per German EHV, §6) Changes shall be collected and reported annually or together with the next significant change (whatever comes first).
• Inclusion of source streams or emission sources not previously covered in monitoring plan • Change in the tier applied • Change in monitoring method, e.g. from standard method to mass balance or from standard method to CEMS • Change of measuring device, if the evidence of compliance with the required tier changes (except replacement of a measuring device with a calibrated measuring device) • Change of a laboratory (except change to a laboratory accredited according to DIN EN ISO/IEC 17025) • Change of sampling plan with regard to applied standard, procedure for sampling or sample preparation, reduction in frequency of sampling • Reduction in frequency of analysis • Change in the category of installation or the classification of source streams that result in higher tier requirements that must be met for source streams	• Changes of address or contact person for the plant or changes of responsibilities within the facility • Capacity change of an installation without change of the emission permit and without inclusion of new emission sources or source streams, change of plant components or technologies used in the plant, change of the plant category or the technologies used in the installation or the category of the installation or classification of source streams that do not lead to higher tier requirements compared to the approved monitoring plan • Change of the assigned laboratory, provided that an accredited laboratory within the meaning of Art. 24 Para. 1 of the MVO has been assigned is commissioned • Change in the collection of data by the supplier, if it is ensured by stipulations in the monitoring plan it is ensured that the specifications of the MVO are complied with and evidence of this is provided
Source: MRR, EHV.	

Apart from the above-described provisions to notify the competent authority of changes to the monitoring through updates of the monitoring plan, there is also the requirement to revisit the monitoring concept based on a regular basis including the notification of the competent authority regarding the implementation of outstanding improvements.

Such outstanding improvements can originate from a relevant ⇒request by the verifier [II.4.2.4], or are defined through a conditional approval of a monitoring plan by the competent authority.

Table 3.2.1b: Improvement reports

<table>
<tr><th colspan="4">Improvement reports shall generally be prepared on a routine basis and upon request from the side of the verifier or the competent authority. The respective provisions for that are listed below.</th></tr>
<tr><td>General principle</td><td colspan="3">All operators “shall regularly check whether the monitoring methodology applied can be improved.” (MRR, Art. 69, para 1)</td></tr>
<tr><td rowspan="4">Prepared on a routine basis if requirement by the MRR are not met (MRR, Art. 69, para 2–3)</td><td colspan="3">The improvement report here demonstrates, if necessary, the disproportionality of the level compliance under the then current circumstances. If tier can be complied with now or in the foreseeable future, the plant operator submits a proposal to DEHSt in his improvement report as to when the necessary monitoring changes will be implemented.</td></tr>
<tr><td colspan="2">Reports have to be prepared if
• the monitoring for large or small source streams at Category B and C installations has not yet complied with the highest tiers pursuant to MVO.</td><td>Every year (Cat. C installation) or every two years (Cat. B installation)</td></tr>
<tr><td colspan="2">• the monitoring at Category A installations has so far fallen short of the relief already permitted by the MVO.</td><td>Every four years</td></tr>
<tr><td colspan="2">• in case a fall-back monitoring methodology pursuant to Art. 22 MVO is applied.</td><td>Every year (Cat. C installation) or every two years (Cat. B installation), every four years (Cat. A)</td></tr>
<tr><td colspan="2">Prepared due to non-conformities or recommendations in the verification report (MRR, Art. 69, para 4– 5)</td><td>A report has be prepared, if the inspection body documents in his inspection report open non-conformities or recommendations for improvement if the monitoring. This does not apply for operators with emission <25kt CO_{2e} per year.</td><td>In the year the verification reports points to such issues.
The report is not necessary if a revised monitoring plan has been handed in that addresses the issues raised.</td></tr>
<tr><td colspan="4">Source: MRR.</td></tr>
</table>

3.2.2 Ad-hoc notification on ongoing monitoring to competent authority

The MRR defines reporting requirement also throughout there year. Art. 45, para 1 refers to the case that parts of the measurement equipment within a CEMS may be out of operation. If that lasts for more than five consecutive days in any reporting year, the competent authority shall be informed without delay. Moreover, the operator shall propose adequate measures to improve the quality of the monitoring system.

That way both sides may early agree on how to derive and apply replacement values and on how to improve the monitoring concept as such. Art 45, para 3 also states that in case of significant technical changes at the installation the determination of substitution values shall be impossible, “the operator shall agree with the competent authority a representative timeframe for determining the average and standard deviation, where possible with a duration of one year.”

3.2.3 The emissions report and its supporting documentation

The emissions report shall be complete. For example, for the monitoring plan there is a definition of minimum contents for the report (see MRR, Annex X). As the report is based on the monitoring plan, most essential information is already automatically included in the report. The report itself follows the same structure as the monitoring plan.

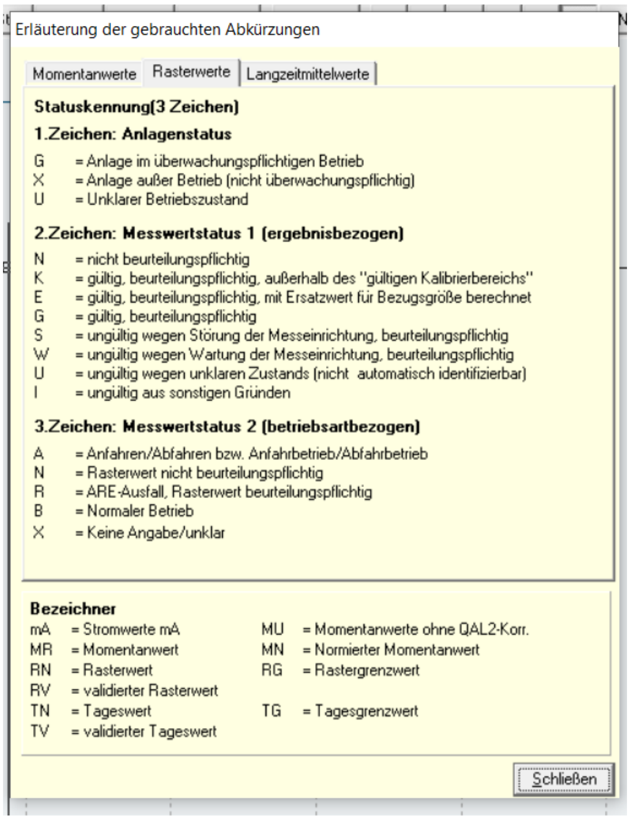
The table below lists most relevant additional information in the report regarding general information and N_2O emissions reporting data including the supporting documents that have to be prepared and handed in by the operator. The report thus also completes/updates general information contained in the monitoring plan. In the end the report, including the verification documentation, shall lay down a complete, transparent and comprehensible description to the monitoring results.

Table 3.2.3a: Reported data and supporting documents to the report

The following regular accounting and supporting documents have to be prepared, gathered and submitted to the verifier with the emissions report, meeting the reporting requirements as defined by the monitoring plan. Please also refer to Table II.2.3.1a for an introduction to the elements of the monitoring plan.	
ASPECT	Data points and SUPPORTING DOCUMENTS
On the adherence to the approved monitoring plan	The report contains version number/date of latest approved monitoring plan including date from which it is applicable (basis of reporting) AND reference to and version number of any other monitoring plans relevant for the reporting year (if applicable); Relevant changes in the operations of an installation and changes as well as temporary deviations that occurred during the reporting period to the monitoring plan approved by the competent authority are clarified; temporal or permanent changes of tiers, reasons for those changes, starting date for the changes, and starting and ending dates of temporal changes are made clear. ➔ VALID MONITORING PLAN including its attachments ➔ APPROVAL NOTIFICATION FOR THE MONITORING PLAN by the competent authority ➔ ALL RELEVANT COMMUNICATION WITH COMPETENT AUTHORITY
Measure-ment instru-ments	➔ The current version of the PROCESS INSTRUCTION ➔ TEST CERTIFICATES for annual control of the measurement equipment On CEMS: ➔ QA DOCUMENTATION: QAL1 certificate, QAL2/AST reports ➔ CUSUM CARDS on the regular quality controls ➔ If relevant for HUMIDITY IN THE OFFGAS: TEST REPORTS ➔ PARAMETER PROTOCOLS FROM THE CEMS, confirming the implementation of the correct values
Reporting of N_2O emissions	The emissions report reports emission of the facility in total (including emissions during downtimes). For downtime intervals though certain information like the number of hourly values with replacement values is indicated. On N_2O emissions measurement ➔ CVS files with hourly raw data from the CEMS ➔ INTEGRATION OF HOURLY EMISSIONS DATA (per applicable calculations) ➔ UNCERTAINTY CALCULATION confirming that tiers are met in the reporting year On N_2O transfer ➔ Documentation of SUBATMOSPHERIC PRESSURE IN TRANSFER TUBE
Source: MRR	

The CEMS raw data deliver the relevant hourly information that is required for the calculation of the N_2O emissions. The table below explains various kinds of status indicators that show up in the hourly readings of a CEMS.

Table 3.2.3b: Status indicators in automatic readings

<table>
<tr><th colspan="2">The CEMS system with automated calculation and application of default values use tags in their readings to indicate which status applies. This table gives an example and explains different relevant status signals.</th></tr>
<tr><td>Status indications table for an CEMS (EXAMPLE/screenshot from a system)</td><td>Explanation of relevant status indication for readings of N_2O concentration and volume flow</td></tr>
<tr><td>


</td><td>
The status indicator below tags hourly values that are valid measurement values during normal operation.
GGB: Plant operation hour subject to accounting; valid, normal operation
The following status indicates hourly values that are accepted as measurement values, although their values lie outside of the calibration range. This is due to the fact that the overall uncertainty in the measurements for the reporting year has been confirmed:
GKB: Plant operation hour subject to accounting; valid but outside of calibration range, normal operation
The following tags hours that are invalid and thus replacement values have been calculated and applied.
GIB: Plant operation hour subject to accounting; invalid (no reason), normal operation
GSB: Plant operation hour subject to accounting; invalid due to disturbance, normal operation
GWB: Plant operation hour subject to accounting; invalid due to maintenance, normal operation
Lastly, there are tags for hourly values where the plant was out of operation. In the readings the do not show up.
XNN: Plant not operating during hour (not subject to accounting -> no value)
</td></tr>
<tr><td colspan="2">Source: FutureCamp.</td></tr>
</table>

3.3 The issue of sanctioning

The German TEHG (section 5) describes various sanctions that shall apply in case the operator does not comply with requirements of his reporting obligations. It includes the following:

- For operators that miss the deadline for emissions reporting in any calendar year, its certificates account is blocked. This sanction is lifted after the respective report is handed in.
- In case a company misses out on surrendering sufficient certificates by the deadline for compliance (30 April), this is sanctioned by charging 100 EUR per ton of outstanding certificate. Only in case of *force majeure,* the competent authority may waive this sanction.
- Moreover, the competent authority may charge fines for incorrect, incomplete, or late reporting where reported emissions are not in line with the approved monitoring plan. This may include cases where the competence authority discovers a breach of due diligence obligations as e.g., ancillary provisions in the approval notification are ignored or wrong information have been submitted etc. Penalties can be as high as 500,000 EUR or 50,000 EUR (the latter in case of negligence).

- For obstruction of the work of the competent authority (e.g., through ignoring request for clarification or submission of documents) fines may reach 50,000 EUR.

3.4 Differences compared to JI and lessons learnt

Table II.3.3: The differences

The aspects below highlight a couple of relevant differences between the EU ETS and JI.	
The annual reporting cycle	The reporting in the EU ETS contains more layers of reporting. As shown above these involve also accounting processes that are focussed on the implementation of an improvement principle. In the offset world reporting cycles may be flexibly planned, may even cover multiple years. This may generate the problem that learning effects may come in too late and thus general accounting risks could be higher.
Digitalization /templates	In Germany the competent authority uses a dedicated data management system with well-defined templates for both monitoring and reporting. In the offset world there used to be a standard of working with word document for both the monitoring concept (PDD) and the monitoring/emissions report.
Mature reporting	Offered CEMS in today's markets are much more transparent than what they used to be 10 to 15 years ago. Even fully automatized today (including the calculation and application of default values) they deliver well traceable information for the emissions reporting.
Sanctioning	In the EU ETS there are relevant sanctions in place. This is due to its character as a compliance market.

Lessons learnt

On the reporting cycle having dedicated timeframes with deadlines for reporting of emissions seems helpful for maintaining a well-structured monitoring and reporting. It may be seen as one supportive component for good governance as it helps the competent authority doing its job as relevant institution for confirming monitoring and verification results and keeping the quality in reporting high. With all reports coming in at a certain date and by making use of digitalized data management (big data) it may much more easily check relevant data. Moreover, the digitalized formats reduce red tape and help assure that the margin of error (e.g., from manual transfer of information from plans into reports) is reduced.

The differentiated reporting cycles can generate special benefits on the operators' side. The separation of the improvement cycle (annually, biannually or every three years) from an emissions reporting cycle allows for a focus on either reporting (of past information) or improvements of the ongoing reporting (for future reporting) based on critical insights from past reporting.

Having sanctions in place to react to non-compliance or to reduce the incentive for gaming/incomplete or opaque reporting seems well-advised – especially in today's markets with high CO_2 prices. This is important in light of deviations/different handling requirements of individuals which could lead to market distortions amongst competing companies. Moreover, it may affect the functioning of the market.

4 Verification requirements

In our discussion of responsibilities and timelines we have highlighted the relevance of the role - of both verifiers and the ⇒ competent authority [II.1.3.2]. This chapter presents relevant solutions and aspects that should be considered when thinking of checks and safeguards through verification which are required to maintain the fundamental integrity in the system.

4.1 Institutional setting and accountability issues

On the regulatory side at the centre there is the ⇒Accreditation and Verification Regulation (AVR) [II.1.1.1]. In combination with dedicated international standards, it forms a comprehensive legal framework that regulates organizational and competency aspects for verifiers, procedural requirements for the verification and requirements for the accreditation of verifiers and the accreditation bodies themselves.

Table II.4.1: The AVR and relevant standards

Below we sum up the major elements in the regulatory framework that rules the verification & accreditation in the EU ETS.	
The EU regulation and guidance	International standards
• EU AVR (Accreditation and Verification Regulation) • Guidance documents (legally not directly binding but useful for interpretation, regarding best practice); these can be found at: http://ec.europa.eu/clima/policies/ets/monitoring_en#tab-0-1. – Explanatory Guidance Document No. 1 – Scope of verification (Key guidance note (KGN) II.1) – Risk analysis (KGN II.2) – Process analysis (KGN II.3) – Sampling (KGN II.4) – Site visits (KGN II.5) – Contents of verification report (KGN II.6) – Competences of verifier (KGN II.7) – Relation between EN ISO 14065 and AVR (KGN II.8) – Time allocation in verification (KGN II.12) – Verification of CEMS (see chapter 6, MRR Guidance document No. 7)	• DIN EN ISO 14065: Accreditation standard • DIN EN ISO/IEC 17029: Conformity Assessment – General principles and requirements for validation and verification bodies • DIN EN ISO 14064-3: GHGs: Specification with guidance for the verification and validation of greenhouse gas statements • ISO 14066: GHGs: Competence requirements for greenhouse gas validation teams and verification teams

Only verifiers that are accredited for specific sector activities at the time of finalization of the verification report may submit their testate.

The accreditation helps establish a non-arbitrary process to check and maintain high quality of the verification regime. Any verifier may lose his accreditation temporarily or permanently in case of misdeeds (e.g., fraud) or lax implementation of the quality requirements as established by the Regulation. To assure the independence and to support a critical attitude (unbiased by routines) the verifiers' lead auditors shall change at the very least every 5 years (rotation principle, AVR Art. 43, para 8).

Please also see Annex II.4 for a discussion in a nutshell of the verification regime including the accreditation of verifiers in the EU ETS.

4.2 Testate or what is to be certified

The certification shall clarify whether a verified emissions report still contains material misstatements. Only if these are absent the ⇒integrity [II.1.2.2] of the reported emissions is assured. Therefore, the verification report directly states whether the emissions report either is "satisfactory" or "not satisfactory". There must be sufficient knowledge and evidence to substantiate this judgment – thus verifiers must apply a high degree of diligence in the execution of their work. Only for certain exceptions can the judgement stating "satisfactory with annotations" apply.

The verifier must describe all non-conformities (deviations from the approved monitoring plan or where the approved plan breaches provisions of the regulation.) Such issues of non-compliance or any issue of non-conformity in a report will require the operator to address these issues in a revised monitoring plan or to discuss them in an ⇒improvement report [Table 3.2.1b].

Risk assessments play an important role. At the contract stage the verifier uses an initial(and subsequently refined) assessment to understand the likelihood of misstatements or non-conformities in the report. This risk assessment is based on a broader strategic analysis where the verifier systematically analyses the complexity and requirements of the verification task at hand. Based on the outcome of this analysis the verifier plans necessary steps in his audit plan – ensuring that he does not oversee critical deficiencies in the operator's reporting.

4.3 Site visits

There is a special value in site visits. Only an onsite review and check-up of system boundaries that are applied to the monitoring of the measurement equipment used can be adequate. Moreover, through interviews, the testing of equipment and data flow (on the basis of a sample) the auditor can understand how the monitoring and data processing is actually executed. Site visits are standard elements in the verification process for this reason. Only under special circumstances and based on approval by the competent authority can the requirement of having site visits be waived.

4.4 Standard verification items

The central verification work is called "process analysis". Based on the iteratively refined risk analysis, the verifier checks the data flow, looks at control activities and procedures (properly implemented? sufficient?). He also applies data testing, examines the analytical basis of data and checks aspects of correct application of the defined monitoring methodology (see KGN II.3).

There are additional checks the verifier has to perform when evaluating the application of CEMS. In the following sections, we focus on several central aspects in the verification work.

4.4.1 Data flow

Any verifier must understand how data is processed from primary raw data to the final emissions data. For CEMS this includes -

- The location of measurement points in the duct system.

- The dealing with variations (e.g., data beyond the measurement range).
- The transfer of data readings to the data management system.
- The calculation and data aggregation.

In practice the data flow is actually ⇒tested at the hand of real monitored data (alternative sentence can be –'In practice the data flow is actually tested using real monitored data' [II.4.4.4].

4.4.2 Control activities

With regard to control activities at installations with CEMS, the verifier has to put special focus on the implementation of the provisions EN14181 defines, including the required ⇒quality assurance [II.2.3.7].

Table II.4.4.2: Verification items on control activities of CEMS

MRR Guidance document No. 7 list verification items for CEMS. The list below is an extract of the most essential of these.
For QAL1 this includes checking whether:
• The conditions at the installation match those defined in the certificate. • All relevant components are properly considered in the uncertainty calculation and whether the latter meets the tier requirements from the approved MP.
For QAL2/AST the verifier is to check – amongst other items whether –
• The defined frequency for QAL2 and AST has been complied with, including timely reaction (recalibration) of identified events from QAL3. • These tests have been implemented by accredited institutions and properly documented. • Results from the QAL2 (confirmed by AST) have been properly programmed in the CEMS.
Verifiers also check the procedures for ongoing quality control (QAL3), i.e., whether – • The procedure is up-to-date, complete (regarding requirements from EN14181) and is correctly implemented and properly recorded in control charts. • Whether steps have been taken in light of these results, e.g., adjustments, recalibration for drifts etc.
Source: MRR Guidance document No. 7.

4.4.3 Process instructions

In monitoring systems with CEMS, an important procedure discusses the closing of data gaps. Further relevant procedures or ⇒process instructions [II.2.3.8] lay down QA measures for the monitoring equipment or the internal data management with processing and review steps (from raw data to the final emissions as reported).
The verifier checks the proper documentation and implementation of these procedures and analyses whether they are appropriate in light of existing risks in monitoring and reporting.

4.4.4 Substantive data testing

For an installation that is not certified as a "suitability-tested evaluation device system" certain aspects need to be analysed. In Germany this is mostly laid down in Annex J of the BEP (2017): "Uniform practice in monitoring emissions and immissions (local pollutants)".

Table II.4.4.4: Verification items on data testing of CEMS

This table presents major aspects that need to be checked during data testing. It refers to the respective parts of core documents where the requirements from the MRR are defined or summed-up.	
Standard hourly values with status assignment	Testing of correct implementation of the 80 % criterion for valid hourly values for concentration, volume flow and for standardization of required reference values: For failure (more than 20 % of the single 2 second values invalid) there shall be status signals like „Fault" and/or „Maintenance" and/or „Raw values out of range" and/or „CEMS out of service". (BEP (2017), Annexes J 1.1, J 1.4, Annex J 1.3 and SKK Paper (2019))
Treatment of hourly values that exceed calibration range	Checking whether substitution values have to be applied for hourly data that is outside of the calibration range: Testing whether the tier requirement for uncertainty in the monitoring year has been met or not. In the latter case default values have to be applied. (Chapter 6.5 of DIN EN 14181; chapter 9.10 of DIN EN ISO 16911-2).
Standard formation of substitution values	We have described these provisions in the ⇒section on downtimes, data gaps and replacement values [II.2.3.6] (BEP (2017), Annex J 2.2 b)
Special formation of substitution values (subject to approval)	For volume flow determination outside the evaluation device (per MRR, Art. 45 para 4) or – where applicable – the automatic substitution value formation may be done by means of a supplementary parameterization of the evaluation device. (BEP (2017), Annex J 2.3)
Source: DEHSt (2021) Guidance for monitoring plans & emissions reports.	

In general, the QAL2 and AST reports (prepared by accredited testing institutions) shall contain all relevant information regarding the application of the above listed requirements in the CEMS. To test the proper implementation of the data calculation in the CEMS, the testing institution shall apply signal path tests for each of the relevant assigned signals and document this in the report: Is the data processing in compliance with the provisions defined by the BEP (2017)? Thus, ETS verifiers may check these comments in the QAL2/AST reports for reference.

4.5 Further facilitation through technical aspects

EU implementation experience shows that technology may help facilitate the verification work.

4.5.1 Integrated data management system for reporting and verification

The past three emissions trading periods have witnessed the competent authority in Germany making use of an online form management system. One essential feature of this is that it fully integrates the reporting (emissions report) and verification part (verification report) into a single document. This effectively supports the interconnection and transparency in accounting. Moreover, as reports are automatically prepared on the basis of digitally imported (approved) MP, the risks of systematic mistakes in reporting are reduced.

This well managed standard data management system (DMS) with interfaces for easy compilation and data processing has further advantages when it comes to the execution of plausibility checks and comparison of data by the competent authority on the macro level. This helps identify more systematic mistakes in the reporting.

4.5.2 Automatized CEMS for simplified reporting

There are CEMS that automatically apply the relevant data processing, extensively presented in sections ⇒II.2.3.4 (following) or ⇒Table II.4.4.4 (above). These are certified systems that have been tested for adequate data processing. The QAL2 reports shall document the proper implementation and functionality of these systems with regards to this automatic data processing.

4.6 Differences compared to JI and lessons learnt

Since the days of JI, both - the maturity of CEMS and the regulatory setting have strongly improved. EU, Germany as well as internationally we have seen many valuable standard documents emerge. For instance currently QA provisions for volume flow are well established and a common practice in EU ETS (⇒II.2.3.10).

However, in EU ETS these improvements materialized gradually. Thus, it is clear that when looking at a best practice for a new instrument, the EU ETS delivers a better reference case than JI - regarding verification as well.

One area where the EU ETS was well "ahead" of JI already at the end of the first decade of this century- was its integrated approach on data management for MRV. The table below sums up these aspects that continue to benefit the quality of the scheme.

Table II.4.6: The differences by application of a mature Data Management System

The aspects below highlight major benefits from using a Data Management System like in the EU ETS. The JI scheme did not have such an elaborate system.	
Integrated data management systems (DMS): a) monitoring plans & reports b) emissions & verification reports c) for easy processing on the macro level	The CDM and JI know standardized reporting templates. But these are WORD documents and lack the rigour that is defined by use of digitalized online templates. Of course, under JI there is no automatic import functionality where a report could automatically be pre-structured based on the monitoring plan. This may be seen as an origin of non-transparency, red tape (auditing is more tedious) and a source of potential mistakes (as data had to be prepared or copied manually). Moreover, in the absence of templates there was also no possible integration of emissions reports and verification reports in one document. Thus, under JI the documentation of the reporting and verification of emissions is less concise and transparent Lastly having a well-managed DMS, like in the EU ETS, may help the competent authority to easily process data. The benefits of digitalization may allow for plausibility checks and thereby help establish a further layer of quality assurance.

Today there are further factors that come into play. One of these is the availability of certified CEMS where the suitable implementation of status signals, the correct parameterization and the correct data transmission is guaranteed and confirmed. This confirmation is already documented by the accredited testing institution that prepares the QAL2 report. With such a fully automatized CEMS in place, the emissions reporting and the verification work may be further simplified. The verifier here just checks the proper application of the quality assurances, the correct parameterisation and the correct transfer of information to the reporting templates – sparing him from majority of data testing.

As authors of this paper have no hands-on experience from implementation cases where such a rigorous CEMS automatization was implemented, they cannot further comment on the viability of this in practice. At the same time dealing with a 'black box' by the verifiers in offset projects (a major cause of concern during audits in the late 2000s is a thing of the past.

Part III: Mitigation options and technologies in EU/Germany On Data -its Availability, Validity and Context

We primarily utilised information from NACAG (*Nitric Acid Climate Action Group)*[27] to write this part.
It proved difficult to obtain further impartial or transparent information of value for this study apart from publicly available information from JI, CDM, GHG Protocol and individual research papers. Market actors such as technology providers treat relevant information with confidentiality. This is due to anti-trust considerations in a market with limited technology providers. They also openly refer to the issue of generalized information on costs and how it cannot be estimated as its contingent on the situation at each single plant.

The following sections focus on information on adipic acid and nitric acid production. There is no experience/data from caprolactam production in Germany as these installations were not covered by the EU ETS and there were no JI projects for these activities. To accommodate the communicated interest by Chinese stakeholders this handbook contains a ⇒special Annex [ANNEX III – Caprolactam] that gives a rough overview on the state of play for these production facilities.

1 N_2O Emissions: Background

In industry, adipic acid is produced by oxidation with the oxidant nitric acid. In the reaction 1 mol of NO_2 and 1 mol of N_2O per mole of adipic acid are formed. While the NO_2 in the off-gas is either returned to a nearby nitric acid plant for reuse or abated due to environmental regulation, the remaining N_2O is inert and of no direct use. For adipic acid plants, the amount of N_2O generated is largely proportional to the amount of adipic acid produced, with a little variation over time and within plants.

27 The NACAG was established by the German Ministry of the Environment. It aims at supporting the application of N_2O abatement technologies through offering technical support on implementation of abatement activities in the nitric acid sector. This also includes supporting the integration of respective facilities into national policies and climate change plans such as national emission trading schemes or inclusion in the NDCs.

Table III.1a: N_2O formation from adipic acid production

The 2006 IPCC Guidelines for National GHG Inventories provide a default value for N_2O formation (300 kg N_2O/t adipic acid with an uncertainty range of +/-10%; IPCC 2006, page 330). The CDM methodology for adipic acid plants uses the lower end of this range as the maximum baseline rate, i.e., 270 kg N_2O/t adipic acid.	
Data source	Rate of N_2O formation (kg N_2O/t adipic acid)
2006 IPCC Guidelines (IPCC 2006) – default value (unc. range)	300 kg/t adipic acid (270-330)
CDP methodology maximum baseline	270 kg/t adipic acid

In the industrial Nitric acid (HNO_3) production, Ammonia (NH_3) is oxidized over precious metal gauzes (primary catalyst) to produce Nitrogen Monoxide (NO) which then reacts with oxygen and water to form nitric acid. N_2O is an unwanted by-product generated at the primary catalyst. The finer a primary catalyst functions, the lower the N_2O emissions. Nitric acid is produced typically across 3-12 months during production campaigns . As the primary catalyst ages, it becomes less efficient and therefore, N_2O emissions tend to increase toward the end of a campaign.

Table III.1b: N_2O formation from Nitric acid production

According to information provided by the Methodologies Panel under the CDM Executive Board in 2012, the N_2O formation rate at Nitric acid production plans varied considerably among CDM plants, ranging from 3.5 to 37.0 kg N_2O per tonne of nitric acid with an average value of 8.6 for all plants (UNFCCC 2012). For JI plants, less information is available. Moreover, most track-one JI projects in Western European countries had to apply a benchmark emission factor of between 1.85 and 2.5 kg N_2O per t of Nitric acid, which is below the common rate of N_2O formation. For new CDP projects 2.5 is also the standard baseline factor for 2020 onward, defined per ACM0019.

Data source	Rate of N_2O formation (kg N_2O/t HNO_3) per plant type, before abatement measures		
	Low pressure	Medium pressure	High pressure
2006 IPCC Guidelines (IPCC 2006)	5 (+/- 10%)	7 (+/- 20%)	9 (+/- 40%)
CDM projects with secondary abatement (2010)	8.52	7.86	9.79
CDM projects with tertiary abatement (2010)	8.24	8.05	10.56
All CDM projects (2012)	8.85 (ranging from 3.5 to 37.0)		
JI projects (2010)	7.33		
Default BL for 2022 (2030) per CDM meth ACM0019 for plants that have applied AM0028 or AM0034 in their first crediting period	3.7 (2.5)	6.6 (5.0)	10.8 (9.2)
New BL value from 2020 onwards per CDM meth ACM0019	2.5	2.5	2.5

Source: Table taken from Oeko-Institut (2014), based on information from IPCC (2006), Debor et al. (2010) and UNFCCC (project information obtained in 2012). The data from ACM0019 is taken from the latest version 4, UNFCCC (2018).

With a Global Warming Potential of 265-298 (IPCC AR4/AR5), N_2O is a potent greenhouse gas and thus subject to various regulations and policy instruments that aim at reducing N_2O emissions to the atmosphere. The key instruments targeting N_2O emissions from adipic acid and nitricacid manufacturing in Europe were introduced in ⇒part I of this document [I]. In chronological order, they consist of -

- Regulating industry to apply best available technologies (BAT) and reduce emission levels below specified thresholds (IPPC directive).
- Offering a monetary incentive by allowing for the generation of valuable carbon credits (JI scheme, voluntary).
- Having plant operators surrender emission allowances for their GHG emissions every year (EU-ETS, mandatory).

Beyond the European Union's borders, the Kyoto Protocol's project-based instruments CDM (Clean Development Mechanism) and JI (Joint Implementation) used to provide an incentive for plant owners to install N_2O abatement technology during 2005-20, with varying intensity due to fluctuating (and eventually decreasing) carbon credit prices. In any case, publicly available data from JI and CDM projects (seven in the case of adipic acid, some 150 in the case of nitric acid) constitutes a rich source for studying applied technologies, abatement levels and costs. This has been comprehensively done by various research institutes in the past and we resort to such existing research in the following chapters.

2 Abatement options

There are a couple of options available for N_2O abatement and have been for several years.

Table III.2: Overview table of Mitigation options

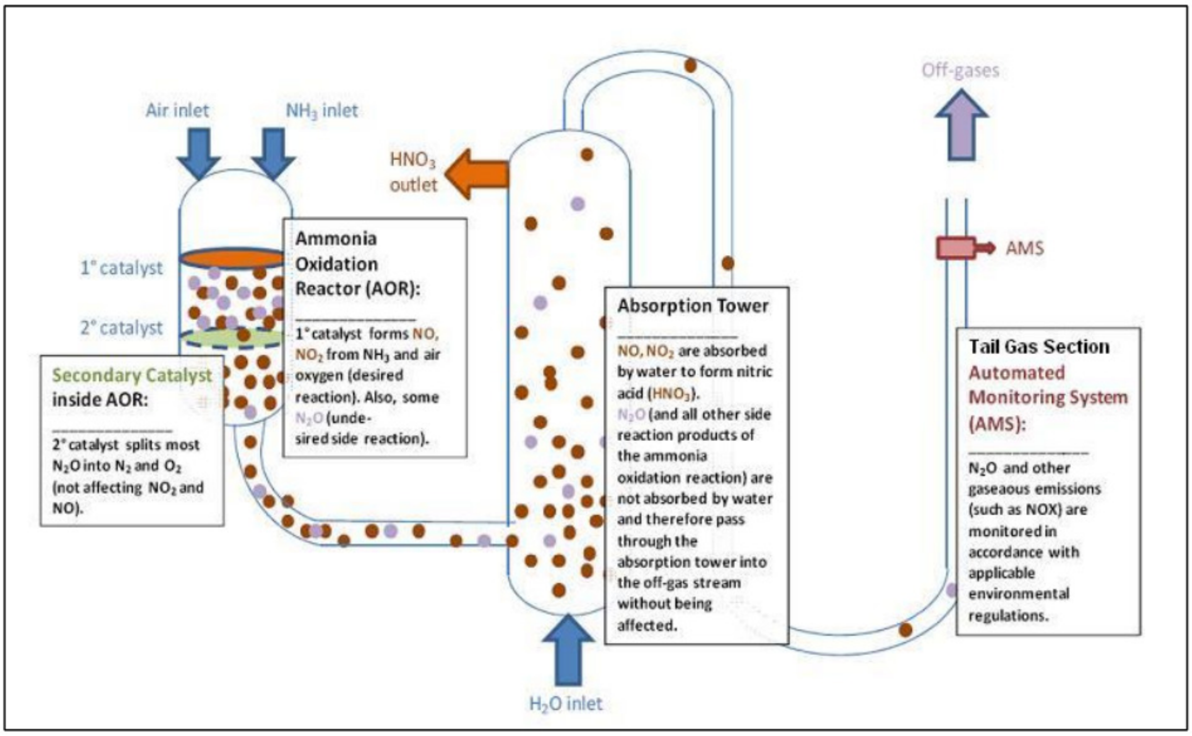
The following table lists mitigation options that are available and applicable in Germany. The spectrum continues to expand as other approaches emerge that complement and improve existing mitigation technologies. For abatement options C, D, E and F we given further explanations in the subsequent paragraphs. Abatement options may generally be combined, e.g., in Germany there are cases where secondary and tertiary abatement is used together.	Production facility/activity	
	Adipic acid	Nitric acid
A) Reuse of N_2O from adipic acid production in nitric acid production: As discussed above, the off-gas contains significant share of N_2O that may be processed in nitric acid production plants. Secondary and tertiary abatement may be applied including further innovative types of reuse (see F below).	■	
B) Primary abatement through improved catalytic efficiency: The regular renewal of the primary catalyst in nitric acid production facilities does reduce the formation of N_2O. Plant operators routinely apply this to maintain a high efficiency level of the production.		■
C) Secondary catalytic destruction: The secondary catalytic destruction of N_2O from nitric acid production is widely applied in Germany and around the world (under the CDM). Here a catalyst in the oxidation reactor destroys the N_2O that is formed in the primary reaction.		■
D) Optimization of secondary abatement: The secondary N_2O mitigation may be enhanced through automatization and other changes in the operation. Here the over-all production, including the conditions for the operation of the catalyst, are optimized.		■
E) Tertiary abatement: The tertiary abatement destroys N_2O by use of thermal or catalytic decomposition in the off-gas of adipic acid and nitric acid plants.	■	■
F) Reuse of N_2O as oxidant/reactant in other production processes: The high concentration of N_2O in the off-gas may be used (after isolation/ concentration) in processes where the N_2O is used as reactant.	■	

2.1 Secondary catalytic destruction

The first-time implementation of secondary catalytic abatement technology usually involves the installation of a basket just underneath the primary catalyst. The basket holds a filling of a selective catalyst that decomposes N_2O into nitrogen and oxygen, at the usual operating temperatures of above 800°C, in the reactor.

Figure III.2.1.1a: Secondary abatement

This figure is taken from ACM0019, depicting the project boundary for a nitric acid plant's project case with installed secondary N_2O abatement measure. This is a simplified standard plant layout, please note that the location of the N_2O abatement catalyst, process sources of N_2O and AMS sampling point location may vary.	Production facility/activity	
	Adipic acid	Nitric acid



Source: UNFCCC (2018), Figure 1.

As the mitigation efficiency of the secondary catalyst degrades over time, plant operators exchange parts of the catalyst granulate or top it with additional pellets - once the abatement rate is too low. BASF, one major producer of secondary abatement technology, indicates a lifetime of 5-10 years for one of its major products. According to NACAG information the replacement cycles in general vary from 3 to 10 years, reflecting abatement product properties and plant conditions. Usually, technology providers guarantee certain levels of abatement efficiency.

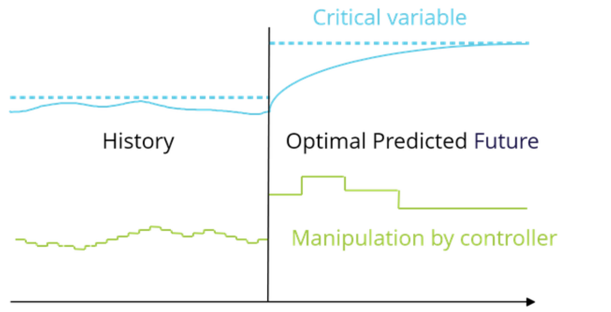
2.2 Enhanced abatement through optimization of secondary abatement

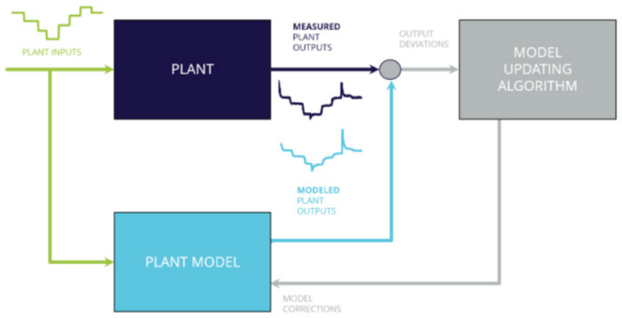
Plant operators with secondary abatement technology may improve the efficiency of the catalytic reaction through optimizing the relevant operating conditions in their facility. BASF has participated in the cross-industry research project

(RECOBA)[28] since 2015 that aims at saving energy and raw materials. This EU funded collaboration under a public-private partnership helped develop and apply cutting edge digitalization technology for process optimization. BASF started with this for optimization of its secondary abatement of N_2O emissions from adipic acid production at its Ludwigshafen site.
Using model-based process control/digitalization tools, the quality specifications for the product together with inputs and outputs in that process are closely monitored, examined, and then constantly controlled and optimized. Tracking an optimal process trajectory may help realize large improvements.

Figure III.2.1.2: Model-based process control

The diagrams below are taken from an online presentation by the Norwegian technology provider Cybernetica that helps implement such improvements at nitric acid production facilities. The results may be more important at sites where the N_2O concentrations are higher (e.g., where adipic acid is recycled; see case A in ⟹Table III.2 above) and the optimization accordingly helps tap a higher emissions reduction potential.	Production facility/activity	
	Adipic acid	Nitric acid
Principle: Couplings between critical variables in the process are analysed and optimized adjustments are calculated.	A nonlinear model predictive control system continuously optimizes the production, thereby enhancing the mitigation results.	





Source: https://cybernetica.no/technology/model-predictive-control/

2.3 Tertiary abatement

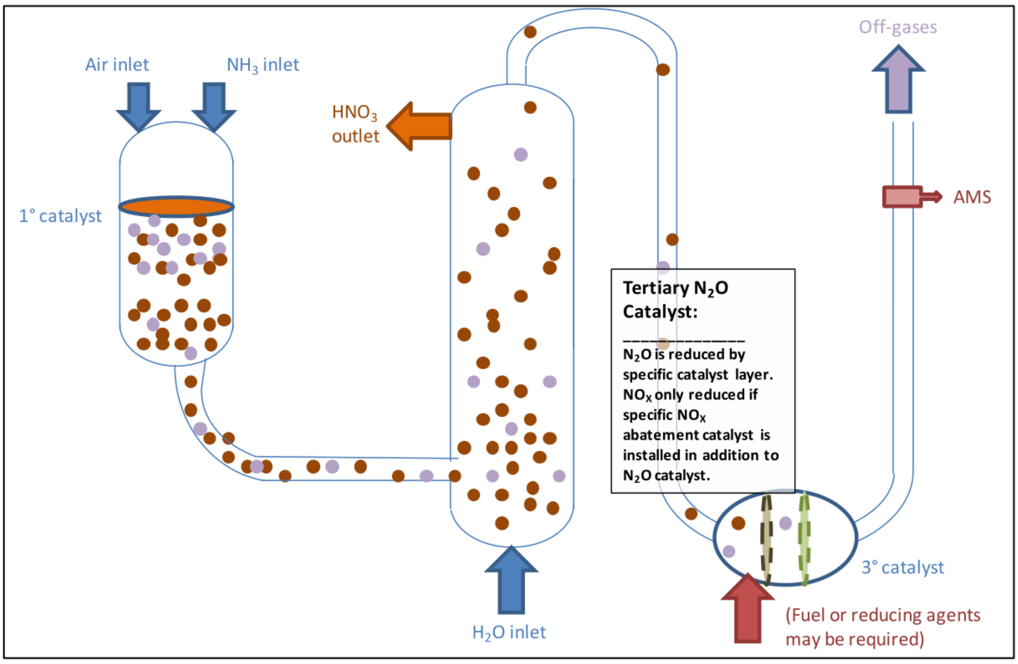
Tertiary abatement means the destruction of N_2O in the waste gas stream of a nitric acid plant. Depending on the technical circumstances and off-gas parameters (temperature, share of N_2O, need to combine with NO_x abatement), different technologies are applied, which can again be categorized in thermal and catalytic N_2O destruction.

The catalytic destruction involves the installation of a catalyst for selective catalytic reduction (SCR) or non-selective catalytic reduction (NSCR). The thermal reduction involves the use of flame burners to destroy the N_2O.

28 Cross-sectorial REal time sensing, advanced COntrol and optimization of BAtch processes, saving energy and raw materials.

Figure III.2.1.3: Tertiary abatement

This figure is taken from ACM0019, depicting the project boundary for a nitric acid plant's project case with installed tertiary N_2O abatement measure. Please also note this is a simplified standard plant layout, thus the location of the N_2O abatement catalyst, process sources of N_2O and AMS sampling point location may vary. The systematics generally also apply to adipic acid production facilities.	Production facility/activity	
	Adipic acid	Nitric acid



Source: UNFCCC (2018), Figure 2.

Both catalytic and thermal abatement technologies are applied for abatement of N_2O from adipic acid production also. One key feature of N_2O abatement in the tail gas is that the actual production process can stay un-touched both during installation and operation of the abatement facility and can theoretically even continue in cases of downtime/failure of the latter. However, since tertiary abatement means the installation and operation of a dedicated abatement facility (possibly including further inputs for operation, like natural gas or ammonia and catalyst), investment and operating costs are typically higher than for secondary abatement at nitric acid plants.

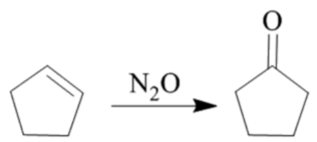
According to data obtained by NACAG 77% of CDM projects registered employ secondary technology, while the remaining 23% use tertiary technology.

2.4 Reuse of N_2O as oxidant/reactant in other production processes

Pioneering processes may help turn nitrous oxide into a valuable raw material for industrial synthesis. The German chemical company BASF invested more than 100 million euros in a new production facility for intermediate cyclopentanone (CPon) and cyclodedecanone (CDon) launched in 2009 at Ludwigshafen, Germany. The highlight of the plant: thanks to a new synthesis path, nitrous oxide will be used for oxidation on a large scale for the first time. The nitrous oxide stems from a different adipic acid production site close-by.

Figure III.2.1.4: Uncatalyzed oxidation of cyclopentene with N_2O

Since 1948 there have been repeated attempts to use nitrous oxide as a selective oxidant. Only in 2009 BASF managed to establish an industry scale express syntheses in CPon/CDon production.



The new technology at the plant is tailor-made for BASF's network. The N_2O allows for an uncatalyzed oxidation of cyclopentene. This alone makes the process sustainable and environmentally friendly (only little waste and wastewater). It proved o be cost-effective compared to conventional production processes. The patented application is significantly more efficient because it only requires three synthesis stages instead of the usual five.

Source: BASF (2010), Ullmann's (2015)

3 Abatement efficiency

In general, the abatement efficiency of catalysts can reach up to 99%. Tertiary catalysts operating under perfect conditions may achieve that as practical experience has shown. LANXESS for example, a German nitric acid producer, disclosed in its 2021 CDP investor communication that it managed to practically eliminate any downtime of the N_2O abatement system and thereby achieved an average abatement efficiency of almost 100%. In all cases, it must be stressed that the efficiency levels that are ultimately achieved for both kinds of catalysts depend on the specific situation and condition of the nitric acid plant.

Table III.3a: Overview of abatement information

The table appended below gathers available information on the abatement rates for the mitigation technology options B/C and E. Please note this data was obtained either from CDM experience or from technology providers .

B) Primary abatement through improved catalytic efficiency:

The regular renewal of the primary catalyst in nitric acid production facilities does reduce the formation of N_2O. Plant operators routinely apply this to maintain a high efficiency level of the production. According to data from 2009, primary gauze improvements may lower N_2O formation by 30-40%.

C) Secondary catalytic destruction:

In general, the achievable abatement rate depends on the design and operating conditions of the nitric acid plant and how the secondary catalyst is installed.

Estimations of the abatement efficiency of the secondary catalyst are in the order of 80% to 90%. However, in practice data from CDM plants indicated poor performance values, as low as 50% approximately. Figures from CDP prior to 2010 only indicated an average abatement efficiency of 70%. From more recent EU ETS and JI implementation experience the authors know that an abatement of larger than 90% is possible and often exceeded. It must be noted though that as the catalyst degrades over time, so does the abatement rate, which decreases– if present measures are taken (see III.2.1.1 above). For example Haereus – one German technology provider – still indicates an abatement rate of 80% after the regular end-of-life of its catalyst has been reached.

E) Tertiary abatement:

The tertiary abatement destroys N_2O by use of thermal or catalytic decomposition in the off-gas of adipic acid and nitric acid plants. According to data compiled in 2010 it can reduce N_2O emissions by more than 90% but involves larger investment,operating costs and more demanding technical requirements than secondary abatement. Figures from registered CDM projects still indicate an average abatement efficiency of approximately 86%. This has improved: According to NACAG data, some providers indicate possible abatement rates as high as 99% (Shell or Clariant). A more recent CDM average for the efficiency of tertiary abatement stood at 94%.

Source: NACAG (2019); Oeko-Institut (2014)

4 Abatement costs and economic incentives

Abatement costs have been studied at different levels for different reasons . A widely used source of data is the project design documents (PDDs) which are (mostly) published during the approval of CDM and JI projects. Also, an analysis of N_2O abatement costs (Ecofys 2009) had been commissioned to inform policy design when adipic acid and nitric acid plants were included into EU ETS in 2013.

Table III.4a: Abatement costs of adipic acid and nitric acid projects (EUR/tCO_{2e})

A good overview of technical abatement costs is provided in a study from Oeko-Institut (2014). We include this table as reference for technical abatement costs under different scenarios (considering different circumstances, like plant sizes and cost variations between countries).
Please note: Total technical abatement costs include CAPEX, OPEX, and revenues or cost savings from the implementation of the GHG abatement (e.g., sales of steam generated from the decomposition of N_2O) on a 10-year basis.

Total technical abatement costs, EUR/t CO_{2e}	Plant/ technology type / Scenario	Adipic acid	Nitric acid (secondary)	Nitric acid (tertiary)
	Low	0.11	0.20	0.79
	Middle	0.29	0.89	3.18
	High	1.19	8.81	11.15

Source: Oeko-Institut (2014)

The stated ranges cover the average costs per ton of CO_2-equivalent that are a result from other studies (Winiwater 2018) and correlate with project-specific experience of their own. For adipic acid the specific abatement costs are very low due to the high N_2O concentrations and thus there is a large mitigation lever present. For nitric acid the costs are higher. In 2018, a dedicated cost analysis for NACAG helped analyse this. It also discussed the cost for technical installation and maintenance of catalytic N_2O abatement systems in nitric acid plants as shown in the table below.

Table III.4b: Abatement costs of nitric acid projects (EUR/tCO_{2e})

This table sums up results from the NAGAG report. Cost ranges are for the initial costs (cost for installation including 2 years of operation/maintenance) and for a subsequent 10 years' period (in brackets). Results are presented for two major technology types (secondary and tertiary) and three different plant cases (small high pressure, mid-sized medium pressure, large-size medium pressure). Several general assumptions have been made during these 300 days of operation and plant utilization rate of 80%. Further, more specific assumptions show up in the table (in italics).

Total abatement cost range, EUR/t CO_{2e}	Technology / Scenario	Secondary abatement Initial 2 years (Subsequent 10 years) Abatement rate: 75 %	Tertiary abatement Initial 2 years (Subsequent 10 years) Abatement rate: 95 %
	200 t/d high pressure plant	3.2 – 3.7 (1.1 – 1.4)	9.1 – 13.2 (0.8 – 1.2)
	500 t/d medium pressure plant	1.5 – 2.0 (0.3 – 0.4)	3.9 – 5.9 (0.4 – 0.8)
	1000 t/d medium pressure plant	1.2 – 1.6 (0.2 - 0.3)	2.7 – 4.1 (0.3 -0.6)

Source: NACAG (2018)

The figures from the quoted studies by Oeko-Institut (2014) and the NACAG initiative (2018) cannot be easily compared especially since the latter study includes more costs parameters including transaction costs for the offset projects. But it seems clear that the cost range, especially for secondary abatement, has narrowed, with a maximum of 3.7 EUR/t CO_{2e} for the initial two years – whereas the study from 2014 indicated almost twice that cost (without including transaction costs).

Results from the NACAG study have also shown considerable upfront cost for the tertiary abatement technology. The abatement rates in the calculation seem quite low (75% for secondary, 95% for tertiary abatement), considering ETS experiences of well above 90% of abatement efficiency for secondary and almost 99% for tertiary technology. It seems fair to say that the cost estimates provided by NACAG are quite conservative.

Based on the two case studies for N_2O abatement projects we included in ⇒part I of this document [I.2] and the summary on abatement costs, given above, we derive a simple conclusion: The installation and operation of N_2O abatement technology at both adipic acid and nitric acid plants become viable economic choices as soon as an installation is covered by compliance regime or when they are eligible for a voluntary carbon pricing scheme with a reasonable price that is set to incentivize action in a carbon market.

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GLOSSARY

The explanation of terms in this glossary is either own or taken/adapted from the sources named in brackets.

Accreditation: Means attestation by a national accreditation body that a verifier meets the requirements set by harmonised standards, within the meaning of point 9 of Article 2 of Regulation (EC) No 765/2008, and requirements set out in this Regulation to carry out the verification of an operator's report pursuant to this Regulation [AVR, Art. 3(2)]

Accreditation and Verification Regulation (AVR): Sets out the rules for accreditation of verifiers by the accreditation bodies within the EU [AVR, Art. 3(3)]

Accredited Independent Entity (AIEs): Auditors, accredited for defined project scopes by the JISC (see JI below) based on international standards. They ensure that the emission reductions meet the requirements of the Kyoto Protocol and the JI Guidelines. See also more broadly the explanation for verifiers below.

Assigned Amount Unit (AAU): An emission right as defined by the Kyoto Protocol. Annex B countries can use AAUs to fulfil their obligations as stipulated in Article 3, Paragraph 1 of the Kyoto Protocol [ETS Handbook].

Automated Measuring System (AMS): See definition of Continuous Emissions Monitoring below.

Best Available Technology (BATs): Advanced techniques to prevent and control emissions in accordance with the greenhouse gas emissions permit [EU ETS Directive, Annex IV, 22b].

Best Available Techniques Reference Documents (BREF): Presents the outcome of the 'Sevilla process'. The majority of BREFs cover specific agro-industrial activities; such BREFs are referred to as 'sectoral BREFs'.

Clean Development Mechanism (CDM): A flexible mechanism under the Kyoto Protocol that allows countries or companies to acquire Certified Emission Reductions (CER) that can be used to meet their own commitments by investing in projects in developing and newly industrializing countries. [ETS Handbook]

Competent Authority: Authority that is in charge managing the emissions trading scheme including review of reports and surveillance of the market. For an extensive explanation of the competent authority including its role in an MRV system with shared responsibilities, please refer to section II.1.3.2. [ETS Handbook]

Note: we also use the term competent authority when discussing the competent authority under JI. In JI terms this body is officially called DFP or Designed Focal Point. In Germany the role is taken over by the DEHSt (German Emissions Trading Authority) that also manages the EU ETS. A list of all national authorities for JI can be found at: https://ji.unfccc.int/JI_Parties.

Compliance: System for checking adherence to reduction obligations, including measures and sanctions to be implemented if a country (in case of the Kyoto Protocol) or operator (in case of an ETS) does not fulfil its obligations to reduce emissions as laid down in legislation of the system. [ETS Handbook]

Continuous Emissions Monitoring System (CEMS): A CEMS always requires the monitoring of two elements, the measurement of the GHG concentration and of the volumetric flow of the gas stream where the measurement takes place. The CEMS automatically protocols and aggregates the measurement data on an hourly basis.

Carbon Dioxide Equivalent (CO_{2e}): Standard measurement unit for accounting of different global warming potentials by relevant greenhouse gas. Carbon dioxide is the reference gas against which other greenhouse gases are measured. According to the IPCC (AR4/AR5) nitrous oxide has a Global Warming Potential of 265-298. [ETS Handbook]

Designated Focal Point (DFP): See competent authority above.

Emissions: Release of greenhouse gases into the atmosphere from sources in an installation […] listed in Annex I of the gases specified in respect of that activity. [ETS Directive, Art. 3b].

Emissions Limit Values (ELVs): Necessary parameters for the basis of calibration and performance checks as an indication of a mass that cannot be exceeded during one or more periods of time. [EU ETS Directive, Art. 60]

Emission Reduction Unit (ERU): Missions credits that are issued for the successful completion of Joint Implementation (JI) projects. [ETS Handbook]

Emissions Report: Document that provides the amount of emitted greenhouse gases of the operator on an annual basis. It needs to be verified by an independent accredited verifier [ETS Handbook].

Emissions sources: Separately identifiable part of an installation or a process within an installation, from which relevant greenhouse gases are emitted […] [MRR, Art. 3 (5)]

European Union Allowances (EUA): Emissions allowances as defined by the European Emissions Trading System. Installation operators use EUAs to fulfil their obligation to surrender emissions allowances according to their monitored emissions. [ETS Handbook]

European Union Emissions Trading Directive (EU ETD): This central Directive establishes the Emissions Trading in the

EU (EU ETS), following the objective to promote cost-effective and economically efficient greenhouse gas emissions inside the EU. [ETS Handbook]

European Union Emissions Trading System (EU ETS): A 'cap and trade' system in the European Union. It caps the total volume of GHG emissions from installations responsible for around 50% of EU GHG emissions. The system allows trading of emission allowances so that the least-cost measures can be taken up to reduce emissions. [ETS Handbook]

European Union Monitoring and Reporting Regulation: Regulation of activity-specific monitoring methodologies for key elements including emission sources and source streams; activity data; net caloric values, emission factors, composition data, oxidation and conversion factors. [ETS Handbook]

Greenhouse gases (GHG): Gases listed in Annex II and other gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and re-emit infrared radiation. [ETS Directive, Art. 3c]

Installation: Means a stationary technical unit where one or more activities listed in Annex I are carried out and any other directly associated activities which have a technical connection with the activities carried out on that site and which could have an effect on emissions and pollution. [ETS Directive, Art. 3e]

Joint Implementation Supervisory Committee (JISC): Supervises the operation of Track 2 and stands under the authority and guidance of the Conference of the Parties Serving as the Meeting of Parties to the Kyoto Protocol. It defines procedural rules apart from those contained in the JI Guidelines, provides templates for project documentation and cares for MRV guidelines and accreditation of Accredited Independent Entities (see above).

Joint Implementation (JI): Was a flexible mechanism under the Kyoto Protocol that allows countries or companies to acquire Emission Reduction Units (ERUs) generated from emission reduction projects to offset their own commitments. JI projects were implemented in countries that have an emissions reduction commitment under the Kyoto Protocol. [ETS Handbook]

Kyoto Protocol: Agreed on in 1997 it committed 39 industrial nations as a whole to a five-percent reduction from 1990 levels in their emissions of gases damaging to the climate between 2008 and 2012 in the first commitment period. It came into force on February 16, 2005. During its first commitment period, the European Union had to reduce emissions between the years 2008 and 2012 by eight percent compared to the level in 1990. [ETS Handbook]

Misstatements: An error, omissions, or misrepresentation in reported emissions data. [MRR, Art. 3]

Monitoring, Reporting and Verification (MRV): Complete, consistent, accurate and transparent monitoring, reporting and verification system that is essential for creating trust in emissions trading. [ETS Handbook]

Operator: Any person who operates or controls an installation or, where this is provided for in national legislation, to whom decisive economic power over the technical functioning of the installation has been delegated [ETS Directive, Art. 3f]. For an extensive explanation of operators including their role in an MRV system with shared out responsibilities, please refer to section II.1.3.2.

Project boundary: For a CDM or JI project activity the significant anthropogenic GHG emissions by sources under the control of the project participant that are reasonably attributable to the project activity as determined in accordance with the CDM/JI rules and requirements. [CDM Executive Board Glossary]

Source stream: means a specific fuel type, raw material or product either giving rise to emissions of relevant greenhouse gases at one or more emission sources as a result of its consumption or production OR containing carbon and included in the calculation of greenhouse gas emissions using a mass balance methodology. [MRR, Art. 3 (4)]

Project activity: means a project activity approved by one or more Annex I Parties in accordance with Article 6 or Article 12 of the Kyoto Protocol and the decisions adopted pursuant to the UNFCCC or the Kyoto Protocol. [ETS Directive, Art. 3i]

Verifier: means a legal person or another legal entity carrying out verification activities; is accredited through an accreditation system. For an extensive explanation of verifiers including their role in an MRV system with shared out responsibilities, please refer to section II.1.3.2.

ANNEXES

ANNEX I-1a – On the use of ETS data in the national inventory

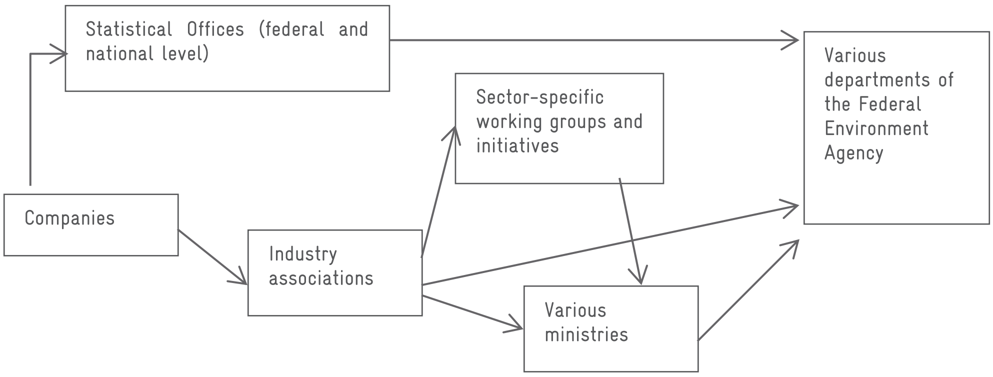
As a party to the United Nations Framework Convention of Climate Change (UNFCCC), Germany has to maintain a comprehensive inventory of national emissions and prepare an annual report (NIR – national inventory report) since 1994. This inventory is the key tool for countries to keep track of emissions over time and – since the Kyoto Protocol – account for the status of emissions compared to climate targets. The national inventory reports shall not only present the results of the inventory, but also contain detailed and complete information on the entire process of preparation of the greenhouse gas inventory, including methods and data sources, quality assurance, uncertainty estimations and retroactive recalculations of data from previous years and the base year (1990/1995).

The most important methodical basis for the preparation of a national GHG inventory is the 2006 IPCC Guidelines for national Greenhous Gas Inventories and the IPCC Good Practice Guidance. Germany has established a comprehensive and sophisticated system of processes and institutions to being able to annually update the national inventory and publish the accordant report, along with the required data, in a timely and reliable manner. This national system has been institutionalised in a process lasting from 2007 to 2011, including agreements between state secretaries of the involved ministries, with federal institutions, industry associations and individual companies.

The key challenge of such a system is obviously the availability of data that can be used to calculate emissions. In line with the IPCC guidelines, emission calculation is based on the following principle:

*activity data * emission factor = emission*

Activity data and, where applicable, emissions data (from own calculation/measurement, ETS monitoring & reporting) find their ways from companies to the competent authority (Federal Environment Agency) via different paths (diagram exemplary):



Under the EU ETS, companies do also annually report emissions to the German Emissions Trading Authority (which is also a department of the Federal Environment Agency). However, as part of the data collection process for the national inventory, no direct or automated link to the ETS data has been established. ETS data are rather used as part of the quality assurance procedures associated with maintaining the national inventory. An accordant workflow has been established between the competent authorities to allow for an annual verification of inventory data using ETS data.[29]

In the case of N_2O emissions, operators of nitric acid and adipic acid plants make individual data (production volumes and emission factors) available to the relevant industry association, which aggregates and forwards them, in an anonymised form, to the Federal Environment Agency. In some cases, companies report directly to the agency, based on accordant agreements. This way, the high tier 3 standard of the IPCC Guidelines is reached. N_2O emissions from the two caprolactam plants are not reported by Germany since they are deemed to be irrelevant.[30]

ANNEX I-1b – JI (2008-2012) in a nutshell

JI under Kyoto: Joint Implementation is one of two project-based offsetting mechanisms under the Kyoto Protocol. It allows a country with an emission reduction or limitation commitment under the Kyoto Protocol (Annex B Party) to earn Emission Reduction Units (ERUs) from an emission reduction project in another Annex B Party, each equivalent to one tonne of CO_2, which can be counted towards meeting its Kyoto target. Joint implementation should thus offer countries a flexible and cost-efficient means of fulfilling a part of their Kyoto commitments, while the host country benefits from foreign investment and technology transfer.

ERUs for AAUs: Under Kyoto Protocol, the countries with commitments (Annex B Parties) have accepted targets for limiting or reducing emissions. These targets are expressed as levels of allowed emissions, or "assigned amounts," over the 2008-2012 commitment period. The allowed emissions are divided into "assigned amount units" (AAU). For every issued

29 See chapter 1.3.3.1.8 of the German NIR 2020.

30 See chapter 4.3.4.2 of the German NIR 2020.

ERU, a host country must cancel one AAU. Thus, if a JI project is over-credited or not additional, the host country would have to make up the difference and engage in more mitigation action.

Track 1 JI: JI projects can be implemented under two distinct tracks. The so-called track 1 procedure – often referred to as a "simplified" JI procedure – is actually the original standard model as envisaged by Parties when drafting the JI guidelines. It allows parties to establish their own rules for approving projects and issuing ERUs, without international oversight. In principle track 1 may be used in any given JI host country that fulfils all the eligibility requirements listed in the JI Guidelines. This status of full eligibility is given though only to parties that among other things have also submitted the required most recent emissions inventory and implemented accurate accounting for AAU. To date, 97% of ERUs have been issued under track 1 – including those for JI projects in adipic and nitric acid plants in Germany.

Figure AI: Key JI characteristics

JI as implemented in the EU and Germany (here: track 1) follows the following features.

- Open for existing CDM methodologies and new project-specific approaches.
- Offset mechanism under the Kyoto Protocol (baseline and crediting type) – facilitating Annex A parties' compliance.
- Built on a bottom-up process for project development.
- Host-country adjusted implementation (JI track 1) along national policy conditions, priorities and interests.
- Bringing potential net benefits to host country mitigation compliance/emissions position in long-term and short-term.

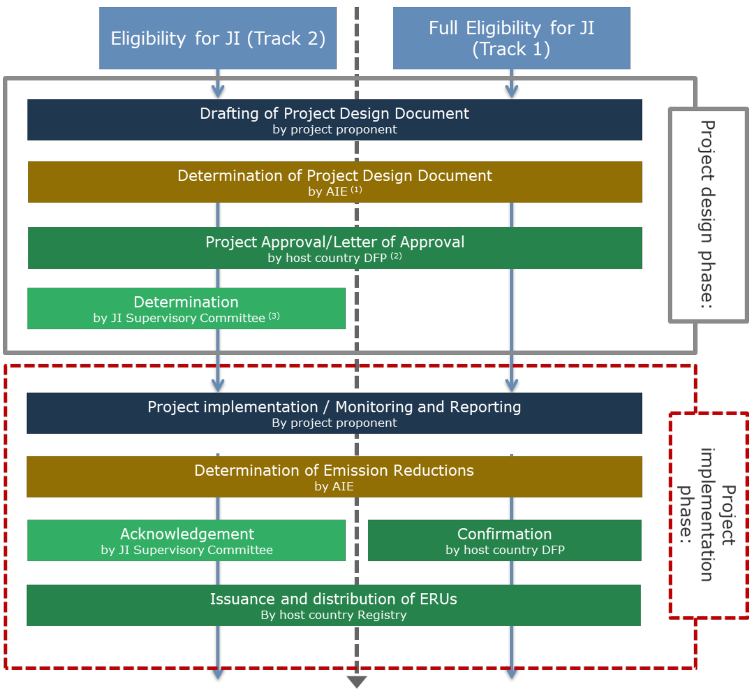


Illustration: FutureCamp 2022/2016

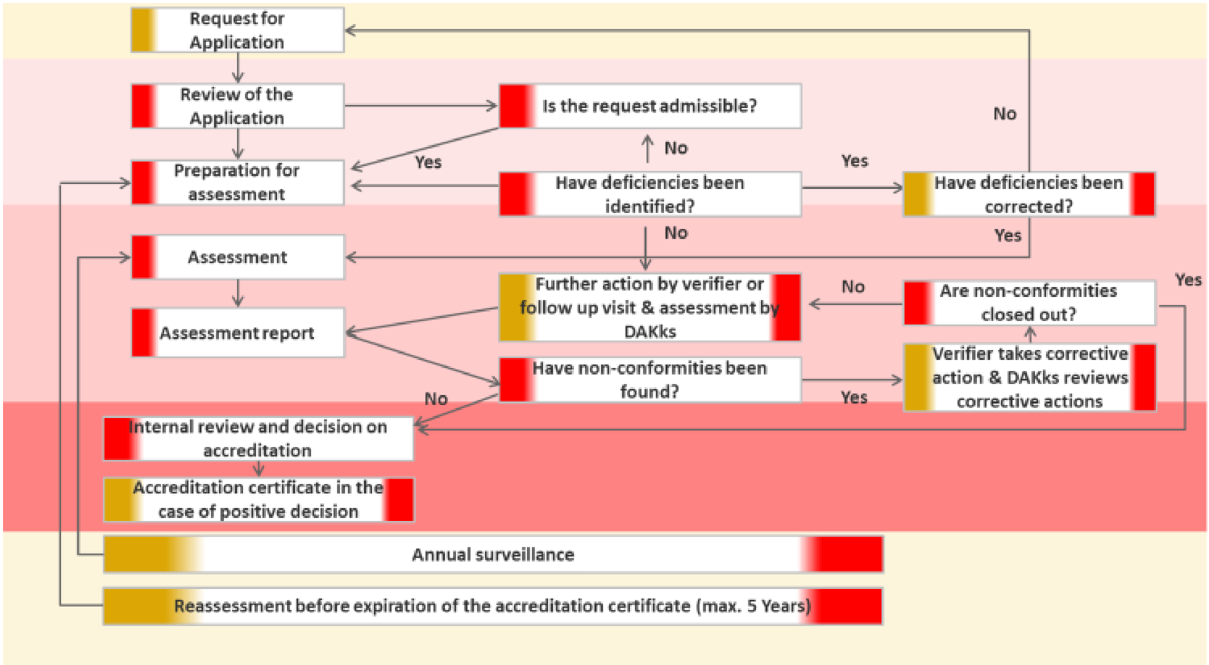
ANNEX II-4 – Accreditation system in a nutshell

On the regulatory side, the EU ETS uses an integrated system with accredited verifiers for the execution of the verification work, a national accreditation body (in Germany: DAKks) that manages the accreditation and the ongoing quality assurance of the verification and is the competent authority for regulatory control. In this set of ⇒shared out responsibilities [II. 1.3.2] the accreditation itself plays an important role.

Through accreditation verifiers are tested and monitored for their impartiality, their competence regarding technical knowhow; their knowledge of the applicable regulations and for maintaining adequate internal decision processes. Regular reassessments follow the same rules. The standard annual surveillance process typically involves witness audits where DAKks auditors accompany accredited verifiers during the execution of their work and an inspection of the internal management system at the premises of the verifier. Moreover, there may be extraordinary assessments where DAKks auditors conduct an investigation based on e.g., complaints about a verifier. The figure below illustrates the continuous accreditation agenda implemented by DAKks.

Figure AII.4a: The accreditation process

A first-time accreditation process usually takes between 6 to 12 months. It starts with the application by a verifier that leads to its eventual accreditation by the DAKks.



- Verifiers must be accredited at the time of issuing a verification report.
- The accreditation is granted for activities with similar complexity, industry type and technical characteristics. E.g., for monitoring of CEMS auditor teams must be able to make resource of relevant expert knowledge as shown in section II.4.
- If verifiers fail to meet regulatory requirements, defined by applicable rules the DAKks must take action, i.e., temporally suspend it, permanently withdraw its certificate or reduce its accreditation scope.

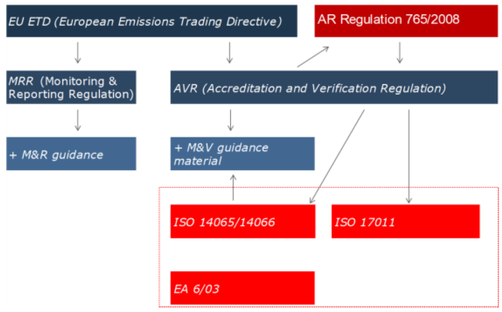
Source: adapted from figure 8 in AVR Explanatory Guidance (EGD I).

The legal framework that displays the accreditation as an interrelation of various regulations and standards. This is illustrated in the figure below.

Figure AII.4b: Legal foundation of Accreditation

ETS Directive as the legal basis for both the MRR and the AVR. EU Guidance documents for both MRR and AVR facilitate the interpretation. This figure explains further AV standards (in red) and their relevance to the legal framework.

- The AVR refers to ISO 14065 as central standard for validation and verification bodies work.
- AR 765/2008 defines requirements for accreditation, accreditation work and composition of the accreditation bodies. The AVR makes some of these requirements ETS-specific (e.g., on competency of the DAKks personnel).
- DAKks in its work follows AVR and AR 765/2008 requirements as well as those found in ISO 17011 (Conformity assessment – Requirements for accreditation bodies [....]). EA 6/03, developed by the EU Cooperation for Accreditation (EA), defines further guidelines and procedures the accreditation body has to follow.
- The interrelation between the AVR and ISO 14065 as well as AVR and ISO 17011 are explained in two specific EU guidance documents (KGD II.8/KGD II.9).



Source: adapted from figure 2 in AVR Explanatory Guidance (EGD I).

On the institutional level, the DAKks has been granted formal recognition and has been authorized by the German Government to execute the accreditation tasks. The accreditation work may also be directly operated by a public authority. Ultimately the DAKks is reviewed by the German government with regard to its competence and performance.

There is also a larger interplay between relevant actors in the framework. Regarding the sharing of information, the DAKks has to inform the CA regarding the suspension of a verifier. The CA on her part has to inform the DAKKs regarding significant errors a verifier has failed to identify during its verification work. This information exchange is important to facilitate a smooth,effective verification and accreditation system.

ANNEX III – Caprolactam addendum

This addendum shortly wraps-up information on mitigation options at caprolactam production plants. It is based on a general literature research and two interviews with experienced representatives from German industry.

Caprolactam and nitric acid production processes are similar when looking at the formation of N_2O. It stems from oxidation of NH3 when NO/NO_2 is obtained for further processing. Thus, N_2O emissions are integral to all caprolactam production processes.

When looking at abatement options, we see the same technological solutions for caprolactam facilities as those discussed for nitric and adipic production facilities. The following three factors are important when considering abatement options at large: First, the off-gas of caprolactam installations is comparatively larger than for nitric acid production. Second, the concentration of N_2O in that gas is also significantly lower; and third, the off-gas temperature in the production of Lactam is lower as well. In combination, for tertiary abatement these aspects mean that much more energy input is required to obtain an effective destruction of the N_2O emissions.

Implementation examples in Germany and Europe clearly show that these special circumstances are no impediment to an application of tertiary abatement technology. Both producers have been using tertiary abatement technology with a redundant design for the past many years in Germany. After the high temperature decomposition, only miniscule residual emissions remain. These residual emissions are so minimal that Germany decided to exclude caprolactam facilities from its national inventory reporting under the Kyoto protocol to the UNFCCC.[31]

One recent innovative mitigation case is the installation of an energy efficient integrated two-step waste gas processing at LANXESS in Antwerp, Belgium.

Table A-III-1: Implementation case LANXESS Antwerp

Exhaust gas purification through regenerative thermal oxidation at LANXESS caprolactam plant where caprolactam is produced as an intermediate for plastics production.	
The two-step purification process	Nitrous oxide is first broken down at 1000 °C into nitrogen and oxygen. In a second step nitrogen oxides (NO_x) are further broken down with Ammonia as a reducing agent to nitrogen and water. This latter step is done at lower temperatures between 250 and 450 °C.
In its external communication LANXESS points to the business case of its innovative technology.	"[…] the plant is highly thermally efficient. This is ensured by specially developed ceramic heat exchangers. These capture and store the heat used in the thermal oxidation process and generated during the breakdown of nitrous oxide and nitrogen oxides. When the heat exchangers have stored the heat from the clean gas, the process flow changes direction, and the heat exchangers now preheat the incoming exhaust gas. This change of direction then takes place recurrently. This means that significantly less external energy has to be supplied to keep the process running."[32]
Investment	10 million EUR
Emission reductions	500 t N_2O/year

Lanxess plans to launch a second facility in 2023, reducing an additional 300 thousand tons CO_{2e}/yr. Similar implementation cases can be found elsewhere in Europe, e.g., at Fibrant in Holland. The company also uses technology from technology provider CTP from Graz, Austria.

31 German Environment Agency (2020) – UNFCCC-Submission: National Inventory Report for the German Greenhouse Gas Inventory 1990 – 2018, p. 319f.

32 LANXESS (2021) "LANXESS inaugurates nitrous oxide reduction plant in Antwerp", https://lanxess.com/-/media/Project/Lanxess/Corporate-Internet/Media/Press-Releases/2021/02/LANXESS_inaugurates_Nitrous_Oxide_Reduction_Plant_in_Antwerp_EN.pdf